Analysis of the Fire Effect on Loadbearing LSF Walls and Design of Experimental Test Setup

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To all that belived in me, my deepest gratitude.

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Abstract

This work present a study of the fire behaviour of loadbearing LSF walls. This study was made with the development of model in finite elements and parametric analysis to evaluete the effects of steel section and plasterboard thickness on the fire resistance. It was also design the experimental test setup for future experimental researchs in IPB facilities.

The model was developed with the use of shell elements for the steel structure and solid elements for the boards. It was made mechanic, termal and termo-mechanic simulations, that were validated with the use of experimental tests results previous realized in University of Queensland. The parametric analysis demostrated that the plasterboard thickness was of little effect in the fire behaviour of the wall, close to 3.5% of increase in the temperature evolution, what can be explained by the composite panel utilized. The steel section thickness however presented a greater influence, 58.15% of increase of the loadbeaing capacity of the wall.

Keywords: Loadbearing LSF walls, Fire behavior, Finite Element model, ANSYS Multiphysics, Experimental test setup

Resumo

Este trabalho apresenta um estudo do comportamento ao fogo de paredes portantes de LSF. Este estudo foi feito com o desenvolvimento de modelo em elementos finitos e análise paramétrica para avaliar os efeitos da seção de aço e da espessura da placa de gesso na resistência ao fogo. Também foi projetada a configuração do teste experimental para futuras pesquisas experimentais nas instalações do IPB.

O modelo foi desenvolvido com a utilização de elementos de casca para a estrutura de aço e elementos sólidos para as placas. Foram feitas simulações mecânicas, térmicas e termo-mecânicas, que foram validadas com a utilização de resultados de testes experimentais realizados anteriormente na Universidade de Queensland. A análise paramétrica demonstrou que a espessura da placa de gesso teve pouco efeito no comportamento ao fogo da parede, cerca de 3,5% de aumento na evolução da temperatura, o que pode ser explicado pelo painel compósito utilizado. A espessura da seção de aço no entanto apresentou maior influência, 58,15% do aumento da capacidade de carga da parede.

Palavras chave: Paredes portantes de LSF, Comportamento ao fogo, Elementos finitos, ANSYS Multiphysics, Configuração de teste experimental.

Summary

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Chapter 1. Introduction

In the recent years, the use of Light Steel Framing structures is increasing in a fast pace, be in a loadbearing capacity or not. The cold-formed steel can be produced in various shapes and sections profiles, this way, being used in a wide array of applications, like floors and walls structures.

However, this type of structure presents one big problem when under fire conditions: the rapid heating of this type of steel leads to the fast reduction of its strength and stiffness. This way, for prevent the failure of the structure in a short range of time during fire events, the LSF structures are commonly used with plasterboard on both sides of the system to fire protection.

Therefore, with the use of LSF structures becoming more common, the necessity of improve the fire safety of this structures in an economic and efficient way is also increasing.

1.1 LSF Walls

Light Steel Frame walls are one of the types of structures in which is used cold-formed steel that presents high loadbearing capacity with low weight of the structure, capable of being used in a wide range of configurations. Formed usually by an array of small elements, the LSF walls are of easy transportation and fast assemble.

The elements commonly used in these walls are panels, studs and tracks. The panels are responsible for the protection of the structure, like fire or impact, and enable the usage of this structure as a partition of the space where it is inserted, the panels are also responsible of bearing horizontal loads and helping prevent the buckling of the studs. The studs are vertical elements that are used for bear the vertical loads, they are connect in the top and bottom by the tracks, horizontal U-shaped elements responsible for the distribution of the loads equally in each stud. With this configuration, it formed a cavity between the panels and the space between studs, in this cavity is usually inserted some material capable of improving the fire and thermal resistance or the acoustic behaviour of the walls, like glass fibre or rock wool. The figure 1.1 shows positioning of each element in the structure.

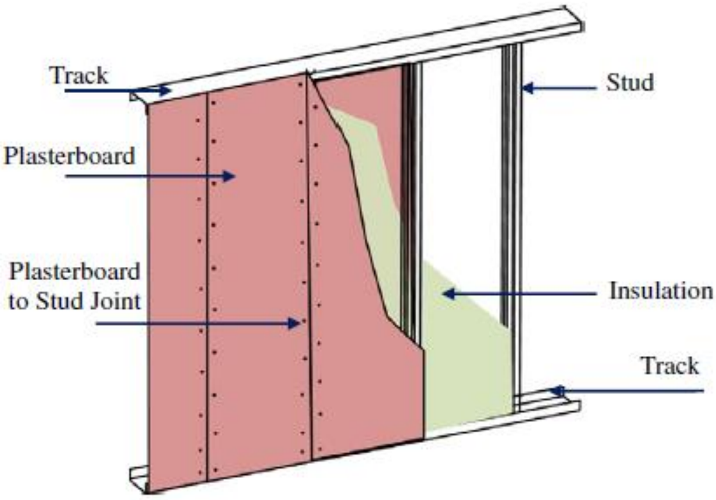

Figure 1.1: Light Steel Frame Wall System

1.2 Objectives

This thesis presents the study of the behaviour of loadbearing Light Steel Frame walls subject to fire events, seeking to improve the knowledge when using different configurations.

Numerical analysis using 3D finite element model with ANSYS software is developed, with the use of different steel sections and spacing between studs as specifics topics to be investigated. The validation of the numerical model is presented.

The experimental test setup is also to be developed and designed, based in the results obtained in the models and the standards EN 1363-1 and EN 1365-1.

1.3 Plan of Thesis

This thesis in divided in six chapters. The second chapter is the state of the art, where is presented a historic review of the use of cold formed steel and the researches about fire safety of LSF walls until now. It is also presented the most used standards and characteristics of fire events, like the heat transfer theory and fire curves in the third chapter.

The fourth chapter presents the numerical model developed in the thesis, specifying the researches used for the validation as well as the elements used and each simulation realized. The validation of the model is also presented in this chapter.

The fifth chapter demonstrates the parametric analysis, with the studies of the influence of the steel section and plasterboard thickness in the fire behaviour of the wall.

In the sixth chapter is presented the design of the experimental test setup structure and the criteria that it should obey. The last chapter presents the conclusion of this work.

Chapter 2. State of the Art

In this chapter will be presented the necessary knowledge on structural and thermal behaviour of Loadbearing Light Steel Frame Walls in fire conditions. It will consist in the historical review of the use and research of this type of structure followed by a brief introduction to the heat transfer theory and fire and finally an explanation of the standards used, including information about the experimental test setup.

2.1 Literature Review

Here is a review of researches about Loadbearing Light Steel Framing Walls in fire conditions. Its presented, in time line progression, experimental studies and numerical analysis about the theme and a summary of the history of loadbearing LSF walls.

2.1.1 Cold Formed Structures: initial studies

The first studies about cold formed structures started in the decade of 1960, when the American Iron and Steel Institute (AISI) sponsored the Cornell University[1] with the objective of identifying the effects of this type of steel work in its mechanical properties and structural behaviour. The research had as finality the potential gain in economy brought by the knowledge of its characteristics, considering that until then, the cold formed structures where design with properties of flat materials, what is not really accurate, since that the forming process leaves to an increase in the yield strength and some reduction in ductility.

This way, the research sponsored by AISI resulted in four papers that together composed the basis for the new provisions in the 1968 edition of AISI's "Specification for the Design of Cold-Formed Steel Structural Members". The papers presented the studies related to the effects of cold straining in structural sheet steel, corner properties on cold formed shapes, the effects of cold forming on light-gage steel members and in thin-walled steel members.

The last two topics primarily were of help in validating the Light Steel Framing construction model by verifying the increase in yield strength brought by the cold forming to this type of structure.

2.1.2 First studies on the Fire Performance of Light Steel Frame Structures

With the constant increase in the use of LSF walls in buildings was perceived the need to improve the knowledge about the fire performance of this type of structure, leading to a growth in the number of researched about the theme.

In 1985, taking the standard ASTM-E119 as subject, Schwartz et al[2] investigated its unexposed surface temperature criteria. In this research the authors realised a series of experimental tests, with the measurement of the unexposed side temperature of each fire test, and ignition tests on several common combustible materials, in order to compare the data with the criteria of the standard. The study evidenced the high safety factor of the criteria and its over conservative stance.

With the increase in use of LSF walls, in 1997 Sultan[3] saw the necessity to investigate the various factors involved in achieving the required fire resistance in this type of structure. Through experimental test of 22 wall assemblies, the authors were capable of ascertain the effects of type and arrangement of studs, existence of resilient Channels, type of insulation, number, arrangement and thickness of gypsum plasterboards. Between all those factors, the ones that showed bigger impact in the fire resistance were the type and arrangement of the gypsum plasterboards and the type of insulation used.

In 2005, Feng et al[4] realized tests on eight full-scale loadbearing cold-formed thin-walled steel structural panels, being two in ambient temperature and six exposed to standard fire conditions. In the research was verified that the failure mode in the fire tests was overall flexural–torsional buckling, with the lateral deformations being mainly caused by thermal bowing due to temperature gradients. One of the main conclusions by authors is the effect of the material used in the insulation on the fire resistance, this was concluded after being observed that the burning of the insulation used lead the panel failure.

2.1.3 The Start of the Numerical Studies

With the beginning of the decade of 1990 studies related to the development of numerical models of the heat transfer in surfaces started to be made. In 1994, Mehaffey et al[5] published a paper were its presented a model to predict the heat transfer on wood framing walls with gypsum plasterboards. The model was validated with small and full scale fire tests and showed capable of predicting the heat transfer well.

Seeing the scarce availability of studies related to the fire performance of loadbearing LSF walls, in 1996 Gerlich et al[6] published a researched with the results of three fire tests and a proposed model for loadbearing walls in fire conditions. For the design of the structural was utilised the AISI Design Manual. The authors conclude that the AISI manual provided the most reliable and accurate source for design of cold formed structures at the time, but still no enough data exist to lead to a precise design to fire conditions. The model developed was capable of reasonable accuracy in the prediction of the fire performance, although refinement was clearly needed. In the same year, determined to characterize the geometric imperfection of LSF structures, Schafer and Pekoz[7] realized studies that concluded a relation between the instability mode of the structure and the geometric imperfection present in the web of the steel cross sections, from this the authors defined empirical equations for the imperfections that are still used today.

Also in 1996, Sultan[8] developed a model for predicting the heat transfer through non-insulate unloaded steel stud walls with gypsum plasterboards exposed to fire. The one-dimensional heat transfer model presented was compared to experimental measured fire ratings and was capable of a good prediction, although conservative (approximately 3% lower than the measured). In 1999, James A. Milke write about analytical methods to evaluate the fire resistance of structural members – later, in 2016, Milke would publish "Analytical Methods for Determining Fire Resistance of Steel Members"[9] – helping in the development of this field.

2.1.4 A brief summary of some of the recent researches of fire performance of Loadbearing LSF Walls

In studies of Gunalan and Mahendran in 2010[10], it was demonstrated that in the numerical analysis of LSF studs the results obtained using the material behaviour as elastic perfect plastic or with hardening effect are considerably close, as local buckling is probably to occur before the hardening relevant. To analyse this affirmation, a series of non-linear simulations was made, each using a different stress-strain behaviour but maintaining the same structure and boundary conditions.

In 2012, realizing that most of the research in the field were mainly to investigate the fire performance of non-loadbearing LSF walls lined with gypsum plasterboards, Wei et al[11] study the effects of different panels on the fire resistance of load-bearing LSF walls. The experimental test was performed with doubled layer boards of the materials: gypsum plasterboard, bolivian magnesium board and calcium silicate. In some of the experimental specimens was used different types of materials for each layer. The results provided a better understanding of the effects of each material in the fire performance of the LSF walls. It demonstrates the possibility of use of the bolivian magnesium board as replacement of the usual gypsum plasterboard due the improvement in the fire resistance, the study also indicates that although the increase in the loadbearing capacity brought by the calcium silicate board the fire performance of the structure is affect because of the combustible nature of the material.

Proceeding with the developments of numerical models, in 2013, taking the results of the thesis of Gunalan[10] as data, the author and Mahendran[12], presents a study with details of finite element models of LSF wall studs developed to simulate the structural performance of LSF wall panels under fire conditions. The finite element analyses were realized under transient and steady state condition. The models were able to predict the fire resistance rating of the experimental specimens quite accurately, what indicates that the model can be used to predict the fire performance of walls of similar constitution, also allowing demonstrate the improvements offered by the new composite panel system in the thesis over the conventional cavity insulated system. Based on the results of the study, the authors assert that the current limitations imposed by the standards are too conservative.

In 2014, Ariyanayagam and Mahendran[13] study the behaviour of load-bearing cold-formed steel walls exposed to realistic design fires through experimental tests. For the fire test was used realistic design fire time-temperature curves, from Eurocode parametric and Barnett's BFD, that represented rapid and prolonged fire situations. The authors conduct eight full scale fire tests on three different types of wall configuration, both single and doubled layers of boards. Besides the comparison between the fire curves and the increased understanding of the response of LSF wall under realistic design fire scenarios, the results of the fire test provided valuable experimental data that can be used in numerical studies.

In 2015, seeking to improve de knowledge about the fire resistance of more structurally efficient stud sections, Kesawan and Mahendran[14] performed fire tests in LSF walls made of Hollow Flange Channel (HFC) section studs. The HFC section stud came as an alternative to the usual "C" section stud, by adding two enclosure spaces inside the "C" section. The tests results were compared to results of regular sections specimens of the same wall configuration. They obtained results that indicate the superior performance and fire resistance rating of the HFC section above the regular sections, they also obtained data that can be used for numerical simulations.

With the development of new technics in the field and seeing that only de structural behaviour of the steel sheathing was researched and its effect on the fire performance of LSF walls was unknown, in 2019 Mahendran and Poologanathan[15] compared the fire resistance of steel sheathed and plasterboard sheathed web-stiffened stud walls. It was realised three full scale fire tests two composed of either steel boards and gypsum plasterboards, and one of only gypsum plasterboards. The results of the study showed that, although the considerable increase in the loadbearing capacity, the influence of the steel sheathing in the fire performance of the walls was minor when compared with only the gypsum plasterboard. This is the case because the rise in the temperature due the opening up of the plasterboard and the steel sheathing, caused by a local buckling in the fire side.

In 2019, Magarabooshanam, Ariyanayagam and Mahendran[16], study the behaviour of load bearing double stud LSF walls in fire conditions. Utilizing three specimens with different load ratios and stud thickness and comparing with similar single stud walls, the authors were capable of identify the reason behind the delayed in the mechanism of heat transfer in double stud walls as the existence of a wider cavity and, mainly, the discontinuous stud arrangement. The research helped to improve the data about the fire performance of double stud walls, until then scarce. The experimental results revealed the enhanced fire performance of this type of structure and also obtained data that can be use in numerical simulation.

This way, is possible to see that the research about the improvement of fire performance of Light Steel Framing Walls can be divided in two topics: the structural influence on the fire resistance, related to stud configurations, stud rows, cross section and web-stiffening, and materials influence, related to the effect of the boards and insulation on the heat flux.

Chapter 3. Fire and Heat Transfer

This topic presents some of the considerations that should be made to realize numerical and experimental studies with fire conditions.

3.1.1 Heat Transfer

As one of the forms of transfer of energy between the object being analysed and its surroundings, heat transfer is generated by the difference of temperature between the several items that form the system.

The heat transfer can occur by three means: the transfer generated by the temperature difference of solids or stationary fluids is denominated conduction, by the temperature difference of surfaces and moving fluids is convection and the last one, in the form of electromagnetic waves, this way being independent of the existence of a medium, is denominated radiation.

Regarding standards regulations, in Eurocode 1, is defined that in the design of structure in fire conditions, in the exposed surface the heat flux should be determined by the summation of convection and radiation, as show in equations 3.1 (convection), 3.2 (radiation) and 3.3 (total). This way, these considerations will be applied to the model development.

$$\dot{h}_{net,c} = \alpha_c \times (T_g - T_m) \ [\frac{W}{m^2}] \tag{3.1}$$

$$\dot{h}_{net,r} = \Phi \times \epsilon_m \times \epsilon_f \times \sigma \times \left[\left(T_g + 273\right)^4 - (T_m + 273)^4)\right] \ [\frac{W}{m^2}] \tag{3.2}$$

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} \ [\frac{W}{m^2}] \tag{3.3}$$

3.1.2 Fire Curves

The fire curves are graphic ways to demonstrate the progression of the temperature during fire events. The natural fire curve is the most appropriated one to describe the behaviour of fire, but the use of the standards fire curves is simpler and of widespread use worldwide.

3.1.2.1 Natural Fire Curve

Describing more precisely the progression of fire, the natural fire curve is divided in three stages, as show in the figure below.

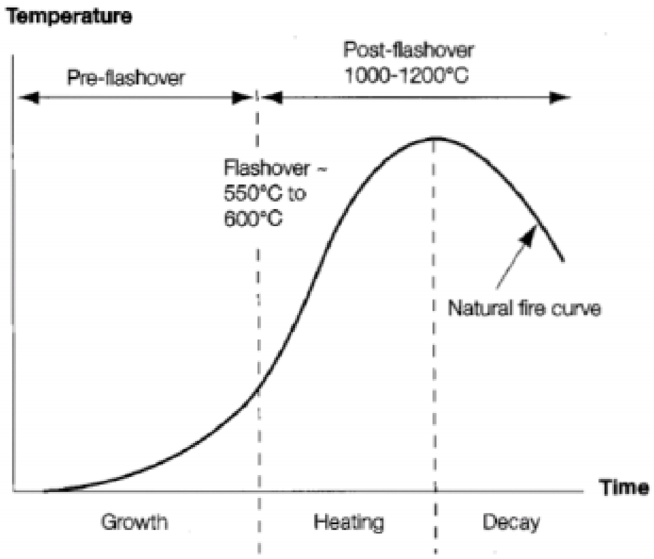

Figure 3.1: Natural Fire Curve[17]

The first stages, although the occurrence of elevated production of gases that are harmful to health, is not of significant influence on the deterioration of the structure resistance, this way it is not included in the standards models of calculation.

The “flashover” is a point inside the between the growth and heating stages where occurs a rapid elevation of temperature, leading to the heating stage, where the highest temperature occurs, being also the stage that the standards curves more adapts.

The last stage is the decay, or extinction, where the cooling of the element starts and goes until the end of the fire. This period is heavily influenced by the material of the element and the ambient where it is included. This stage is also not in the standards models.

Even with the capability of better describe the behaviour of fire, the natural fire curve is not commonly used for the fire resistance calculations, because of the amount of data needed about the material of the structure and the ambient, but is a method that probably will be used constantly in the near future.

3.1.2.2 Standard Fire Curves

As an approach to the natural fire curve, the standards fire curves are methods of demonstrated the behaviour of fire independently of fire load and space. As said before, these models adapt to the “flashover” and heating stages of the natural fire curve, that are the more important periods to the structural and thermal analyses.

In the Eurocode 1 is defined that to structures in fire events it can be used one of the three presented fire curves: the ISO834 curve, defined as standard curve, the hydrocarbons curve and the external elements curve. The ISO834 is the most used in the studies of fire behaviour, this work included.

To the ISO834 curve, the Eurocode establish some considerations, as the coefficient of heat transfer as $a_c = 25\, W/m^2K$ and the equation below as the progression of the temperature, also plotted in the figure 3.2.

$$\theta_g = 20 + 345 \log(8t + 1) \tag{3.4}$$

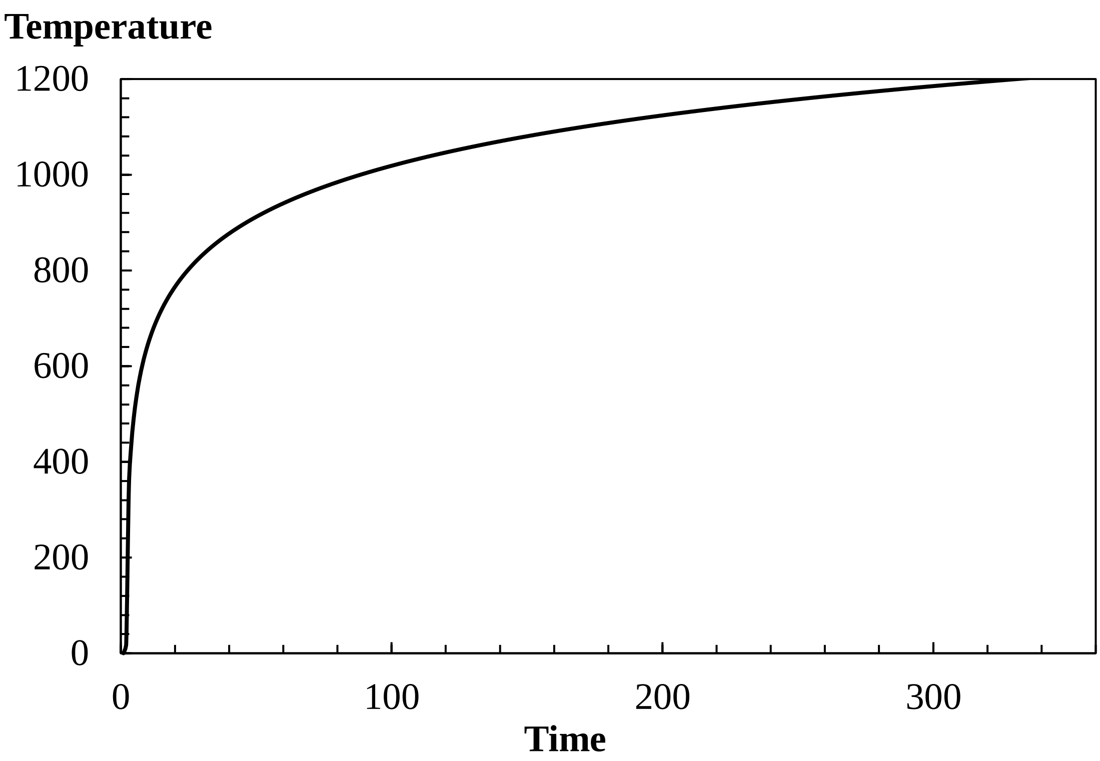

Figure 3.2: ISO834 Standard Fire Curve

3.1.3 Fire Behaviour of LSF Walls

When realizing experimental tests or simulations of fire events on LSF walls is usually exposed one of the faces of the wall to fire, this way, the temperature distribution on the structure is non-uniform. This distribution results in the generation of complex structural behaviour, like thermal bowing and non-uniform strength and stiffness through the cross section of the studs. In turn, the plasterboards used will be heated and degraded with time, leading to loss of the protection and support provided to the studs. With the consumption of the boards, the heating rate of the studs also increase what in turn leads to the increase of the loss of strength and stiffness of the steel, besides that, in the system where are used insulation, this insulation is also burned and consumed in a fast pace. In some cases, the material that form the plasterboard or the insulation can be flammable, what can again increase the heating rate of the studs.

The fire resistance of LSF walls is usually verified with the time of duration in exposure to fire until the criteria failure. This factor depends of several interrelated properties of the boards, the insulation and the steel structure. The standards usually defined the criteria failure as the moment the wall losses its capacity of bearing the load applied to it or its capacity of limit the spread of the fire.

3.2 Standards

In the analysis of the fire resistance of a loadbearing structure, specifically a loadbearing LSF wall, are used the standards EN 1363-1: Fire Resistance Tests – General Requirement, EN 1365-1: Fire Resistance Tests for Loadbearing Elements – Part 1: Walls and Eurocode 3.

3.2.1 EN 1363-1

The standard EN 1363-1 is responsible to present the general requirements of procedures to perform fire resistance tests. It specifies the requirements of the furnace used in the test, the equipment that should be used to control the temperature, the number, position and characteristics of the thermocouples that should be used to monitoring the temperature variation on the specimen, including sketches, as well as the number, position and characteristics of the displacement measuring equipment. The frame which the element will be installed and some special devices to specific cases, like measuring the oxygen concentration are also presented in the standard.

The EN 1363-1 also specifies the performance criteria used in the fire test. This performance defines the fire resistance rating of the element, that is basically the total amount of time in minutes since the beginning of the experiment until the failure in the one of the criteria presented.

There are three performance criteria that should be used: the insulation criteria, the integrity criteria and the loadbearing criteria.

The insulation criteria (I) is defined as the capacity of the element maintain its function without the development of hight temperatures in its unexposed face. This is verified by the condition that the average temperature on its unexposed face do not increase by more than 140 K or any point of the specimen do not have an increase of more than 180 K above its initial temperature. The insulation criteria automatically fail if the integrity criteria fail.

The integrity criteria (E) is considered as fail as the time that the flame or smoke pass through the unexposed side by cracks in the specimen.

The loadbearing criteria (R) is the main performance criteria defined by the standard, it is based in the deformation of the structure and is capacity to support its test load, this criterion should be determined by two methods, where the exceeding of any of them should be considered as the failure of the specimen. These methods are the extend of deflection, as the limiting vertical contraction being defined by equation 3.5, and the rate of deflection, as the limiting rate of vertical contraction as show in equation 3.6, where “h” is the height of the element.

$$C = \frac{h}{100}\ [mm] \tag{3.5}$$

$$\frac{dC}{dt} = \frac{3 \times h}{1000}\ \ [mm/min] \tag{3.6}$$

3.2.2 EN 1365-1

The EN 1365-1 is the standard that presents the procedures to perform the fire resistance test of loadbearing walls and demonstrates some more information about instrumentation and other devices.

The standard specified that the experimental specimens should be fix to a rigid frame, capable of supporting the specimen without interfere with its behaviour, be it thermal or mechanical. It is also specified that the load can be concentric or eccentric applied with the use of hydraulic or mechanical jacks and one rigid interface beam, 15 minutes before the beginning of the test.

The standard also presents information about the instrumentation of the test. For the use of thermocouples, it is specified that should be used one thermocouple for each 1.5 m² of area exposed to fire. For walls with insulation rate expected to be bigger than 5 min, it is necessary the use of thermocouples in the unexposed face of the wall in accordance with the standard EN 1363-1 with the objective of estimate the average and maximum temperature development of the specimen.

The measure of the displacement should be realized as presented in EN 1363-1 for the vertical displacement, the horizontal displacement should be measured with appropriated device in half the height of the specimens, if this displacement is expected to be bigger than 5mm.

3.2.3 ISO834-4

As said before, the ISO834 standard presented the directions to realise fire experimental tests, including the standard fire curve used in the analysis. In the part 4 of this standard, *ISO834-4: Specific requirements for loadbearing vertical separating elements*, presents specific directions to cases like fire tests of loadbearing walls.

In this part, is defined some of the the requirements presented in EN 1365-1, furthermore, is defined requirements about the supporting frame and loading tools to be used.

According to the standard, as a guide, the stiffness of the supporting frame should be enough so that the maximum deflection of the load distribution members be 1mm when a load of 10kN is applied in the centre span, in the plane of the frame.

In relations to loading tools, the standard specifies that in the experimental tests can be used either a loading beam or individual loading jacks. In the case of LSF walls, is commonly used loading jacks positioned in each stud of the specimen.

The specifications on this standard will be used as base to the development of the experimental test setup.

Chapter 4. Numerical Model

In this chapter will be presented the finite element model developed, including a description of the types of finite elements used in the model, each type of simulation that was made and the research used as base for validation of the model.

4.1 Elements Used for the Model

For the modelling of the structure analysed in this thesis was used two types of finite elements, Shell and Solid elements, being further divided in elements with degrees of freedom in each node specific for mechanical analyses and thermal analyses, adding up to three types of elements, as the solid elements were used only in the thermal simulation.

The steel structure was modelled with Shell finite elements and the boards with Solid finite elements. This topic makes an introduction to the characteristics of these elements. It will be used the nomenclature of ANSYS to refer each element.

4.1.1 Mechanical Model

Suitable for analyses of thin-walled structures ANSYS's Shell 181 was the finite element used for the modelling of the steel structure. It is a four-node element with six degrees of freedom at each node – translation in x, y and z directions and rotation about the x, y and z axes. For the model developed in this thesis was used five integration points through the thickness of the element. The figure below shows the node locations, geometry and integration points through the thickness of the element.

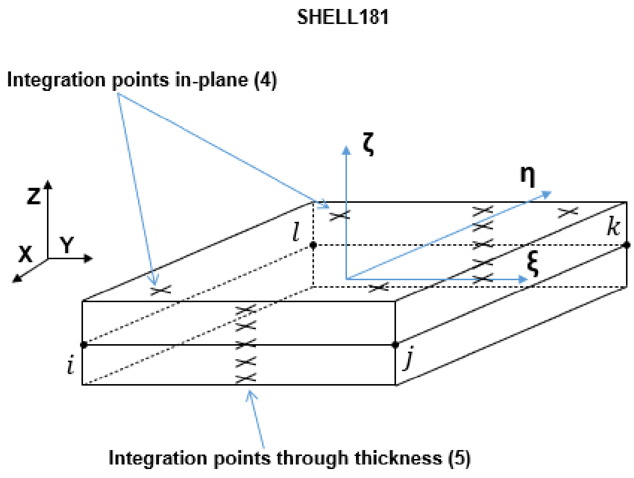

Figure 4.1: Element Shell 181

4.1.2 Thermal Model

The thermal model was developed using the elements Shell 131 and Solid 70.

Such as Shell 181, the Shell 131 is a four-node element, with up to thirty-two degrees of freedom at each node, being only temperature, the degree used in the model, four integration points in plane and at least three through the thickness – five in the model – this way having in-plane and through-thickness thermal conduction capability. The variation of the temperature through the thickness was defined as linear for this analysis. This element enables the application of the results found in the thermal simulation to the Shell 181 elements in the mechanical model.

The Solid 70 is an eight-node element with only one degree of freedom per node, the temperature, having a 3-D thermal conduction capability. This element has eight integration points.

The figures below show the nodes locations, geometry and integration points of each element.

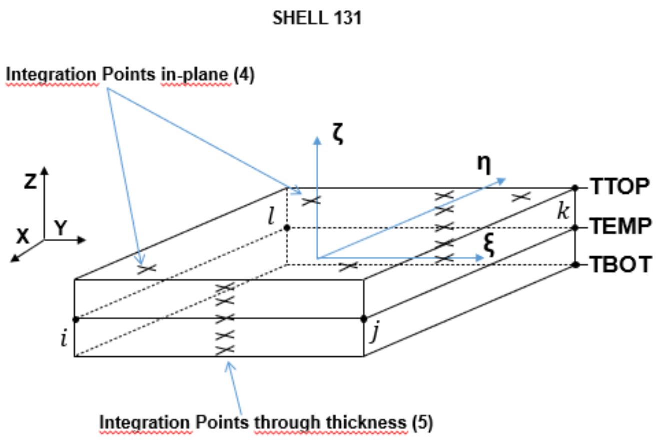

Figure 4.2: Element Shell 131

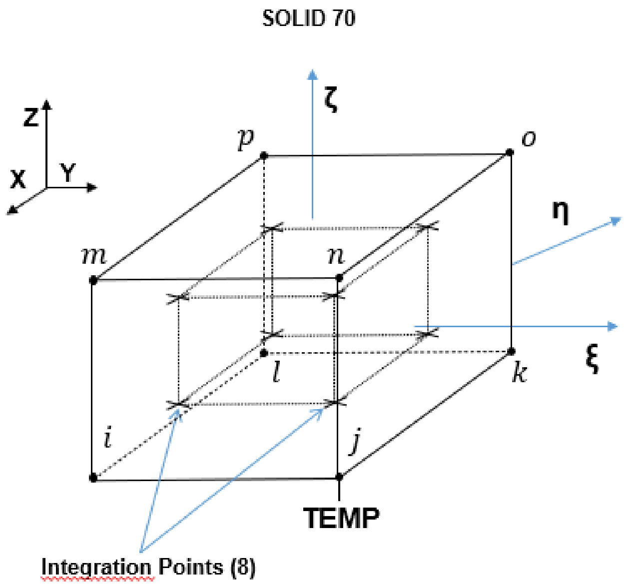

Figure 4.3: Element Solid 70

4.2 Solution Methods

For the development of this thesis was realised four types of simulation: two mechanicals, one thermal and one termo-mechanical.

In this topic will be discussed each analysis made, it's purpose, solution method and some of the boundary conditions applied. The individual boundary conditions of the experimental research used for validation will be approached in the Numerical Validation topic.

4.2.1 Buckling Analysis

The buckling analysis is a linear analysis capable of determine the theoretical buckling strength of an ideal elastic structure, being also known as classical Euler buckling analysis.

Using the eigen-vectors and eigen-values theory, this analysis is of great importance because of the capabilities in determine not only the buckling strength of the structure but also the buckling modes, this way being of great help in the understanding of the capacities and behaviour of the structure by the designer.

The first step in the solution of a buckling analysis is the solution of equation 3.1. The buckling analysis is based in the static linear analysis, with the difference that a reference load, usually a unit force, is applied to the structure and being all the end results a scale of the reference load. This way, based in this assumed load, expressed as $\{F_{ref}\}$, and the stiffness matrix of the structure, [K], the solution of equation 4.1 can be found, where {d} is the displacement.

$$[K]\{d\} = \{F_{ref}\} \tag{4.1}$$

With the displacement found, the stress field in the structure can be determined based on the reference load, generating a stress stiffness matrix $[K_{\sigma,ref}]$ proportional to the load. This way, can be defined a constant λ to define an arbitrary load and stress stiffness matrix as show in equation 4.2 and 4.3. From this point, it can be assumed that a critical load can be determined in this arbitrary load, as appointed in 4.4, and as consequence the equation 4.1 can be rewrite as show in 4.5.

$$[K] = \lambda[K_{\sigma,ref}] \tag{4.2}$$

$$\{F\} = \lambda\{F_{ref}\} \tag{4.3}$$

$$\{F_{crit}\} = \lambda_{crit}\{F_{ref}\} \tag{4.4}$$

$$\Big[[K] + \lambda_{crit}[K_{\sigma,ref}]\Big]\{d\} = \lambda_{crit}\{F_{ref}\} \tag{4.5}$$

As buckling is basically the increase of displacement in the same load level, the equation 4.5 can be modified with the increment of a buckling displacement vector {δd}, as show in 4.6. This way, an eigenvalue problem is created, as in 4.7, where the solution of λ is the buckling load of the structure.

$$\Big[[K] + \lambda_{crit}[K_{\sigma,ref}]\Big]\Big\{\{d\} + \{\delta d\}\Big\} = \lambda_{crit}\{F_{ref}\} \tag{4.6}$$

$$\Big[[K] + \lambda[K_{\sigma,ref}]\Big]\{\delta d\} = \{0\} \tag{4.7}$$

The buckling analysis was realized with the objective of determine the first mode of instability of the structure. This is important mainly, in this case, because of two reasons: the first mode of instability it's a result of the theoretical buckling strength of the structure, therefore, the maximum load before the occurrence of local or global instability that the structure can receive was roughly estimated, the second reason is that the deformation found in the buckling analysis can be used as a method to implement the geometry imperfection in the model for the non-linear analysis.

For this analysis was considered the pre-stress effect present in the structure.

4.2.2 Non-Linear Analysis

As a more accurate method than the elastic buckling analysis, the non-linear analysis considers the non-linear behaviour of the material, imperfection in the geometry and large displacements in static simulations to predict buckling loads.

The solution method used in this analysis is based in the Newton Raphson solution method, that uses increments of load applied in the structure over time, until the structure becomes unstable. This load can be force or displacement. In this work, the two types of load were used in the development of the model. Ultimately, the results obtained by using increment of force was determined to be more accurate in this case and thus are presented in the results section of the thesis.

The nonlinearities were applied using knowledge of previous researches in cold formed steel and LSF structures. The geometry imperfection was determined based in the studies of Schafer and Pekoz[7], using the equation:

$$Imp = 0.006 \times web \tag{4.8}$$

As also suggested by the authors, these imperfections are in the shape of the structure eigen modes, this way, in the model, the imperfection was applied with the usage of the results obtained in the linear elastic analysis. Using the maximum displacement in the web in the horizontal direction, that is usually close to a half sine wave form in the first mode of instability, and Schafer's method of deduce the imperfection, it was calculated a scale factor that multiplying the linear buckling analysis results was obtained a compatible imperfection.

Based in the results obtained by Gunalan and Mahendran [10], resumed in table 1, it was determined that using perfect plastic behaviour to realize the simulations would be possible.

Table 1: Ultimate Load for each material model.

Model	U [kN]
Elastic-perfect-plastic	78,8
Strain hardening	79,2
True stress	80

4.2.3 Thermal Simulation

Considering that it was a transient analysis, using the full method solution, the thermal simulation was used to determine the behaviour of the LSF walls exposed to fire through time. This way, with each increment of time a progression in the temperature occurred.

The thermal simulation was used to identify the variation of temperature of the structure without the influence of an applied load. So, all force applied to the structure was deleted and new boundary conditions were applied.

In the new information inserted in the model was the ISO834 standard fire curve and a curve describing the average variation of temperature in the cavity, measured in the experimental research. This time – temperature curve was used to increase the precision of the results, by simulating the effects of the degradation of the plasterboards and eventual fallout of material.

The heat transfer was applied as defined by EN1991-1-2[18], with transfer by radiation and convection in the exposed face, being emissivity $\xi = 1$ and convection coefficient $a_c = 25\,W/m^2K$, and by convection in the unexposed, with convection coefficient $a_c = 9\,W/m^2K$ in the unexposed (value with the inclusion of the radiation). In the cavity was assumed also heat transfer by radiation and convection, with emissivity $\xi = 1$ and convection coefficient as an approximation of the average of the exposed and unexposed face, this way $a_c = 17{,}5\,W/m^2K$.

4.2.4 Thermo-Mechanical Simulation

The thermo-mechanical simulation is the final objective of all the simulations before. In this simulation, it can be analysed the behaviour of the loadbearing LSF wall with the increase in temperature. This simulation is based in a series of static simulations of the structure through the occurrence of the fire event and presents the decay of the mechanical properties e effects of the thermal properties through time.

This simulation differs from the non-linear simulation by not utilizing an incremental of load method in a direct way. In the simulation, a ratio of the maximum loadbearing capacity of the wall was applied. Considering that in the experimental test the mechanical jacks are set up to adjust to the expansion of the structure to prevent the increase of the load, this applied load had a variation through time to simulate the same behaviour, this way, the force in action on the structure was always constant, so the only variations on the wall capacity were related to the increase in temperature.

The thermo-mechanical simulation was made using the same considerations and boundary conditions of the non-linear simulation. It was applied to the model de results of the variation of temperature on each node found in the thermal simulation as substeps of solution. It was also applied the thermal expansion coefficient of steel and mechanical properties with variation of temperature. This way, with the increase of temperature in the structure, the effects on stiffness and cross section would be considered and for each substep, a new geometry and mechanical properties is used.

4.3 Numerical Validation

4.3.1 Experimental Research: "Structural Behaviour and Design of Cold-formed Steel Wall Systems under Fire Conditions"

The first experimental research used for the validation of the model was the thesis of 2010 by Gunalan and Mahendran named *"Structural Behaviour and Design of Cold-formed Steel Wall Systems under Fire Conditions"*[10]. Using true scale LSF walls with structure of G500 cold formed steel and composite panels of gypsum and glass fibre, this research had the objective of study the effects of composite panels on the fire behaviour of the LSF walls and its use as an alternative to the more common cavity insulated walls. In addition to the experimental results, it was also used the FEA results of the research to analyse the developed model precision.

4.3.1.1 Structure Geometry

The wall specimen used in the study presented four studs of cross section of 40x90x15 mm and were 2400 mm long, spaced between each other by 600 mm, united by a 2.1 mm long tracks of cross section 50x92mm, both the stud's and the track's cross sections had a thickness of 1.15mm. The figures below demonstrate the structure and the cross sections.

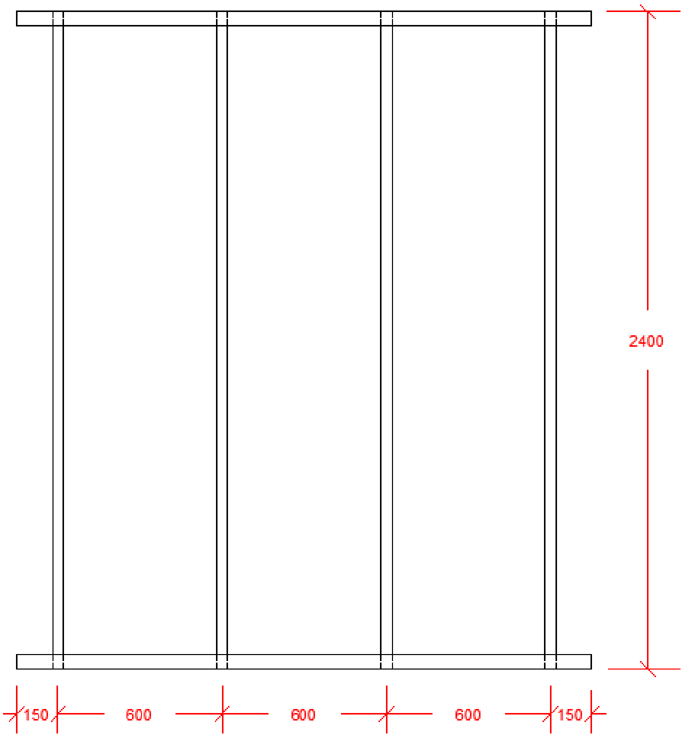

Figure 4.4: Wall Structure.

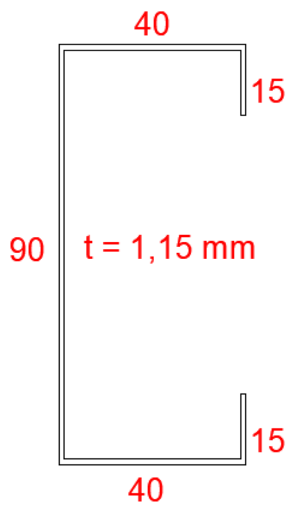

Figure 4.5: Stud Cross Section

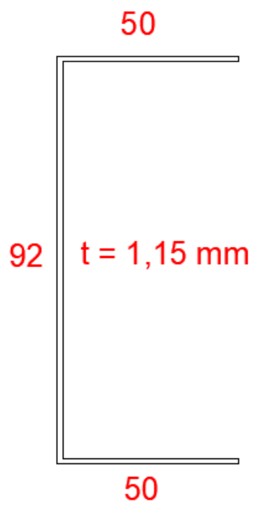

Figure 4.6: Track Cross Section

As usually, the LSF walls had boards for protections and partition effects. In the researches, Mahendran and Gunalan study the use of the composite panels, as an option to the simple plasterboards normally used. This way, the panel used in the specimens were formed by an insulation of glass fibre with 25mm of thickness inserted between two gypsum boards, as illustrated in the figure.

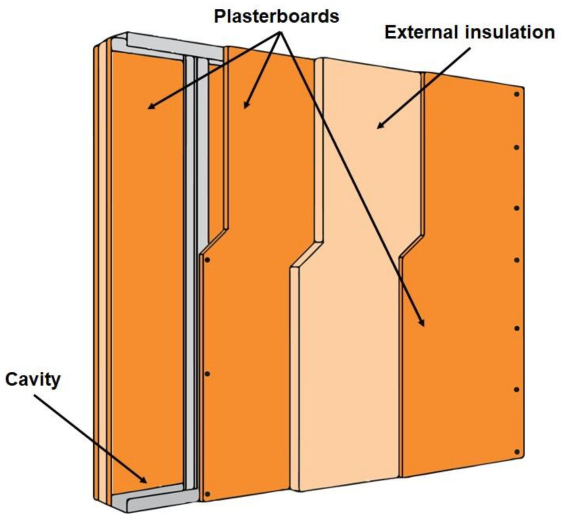

Figure 4.7: Wall Scheme.

4.3.1.2 *Material Properties*

As said before, this research was realised with G500 steel. This type of cold formed steel has a yielding strength of about 500MPa. After experimental tests of the material, the authors determined that it had a yielding strength of 569MPa and elastic modulus of 213,52 GPa. This way, that's was the values used in the model.

For the effects of high temperature in the mechanical properties of the material, it was used the results obtained in Mahendran's study about the subject in 2009. The results obtained by the author are the set of empirical equations below.

$$For\ 20° \leq T \leq 200°C \qquad \frac{E_T}{E_{20}} = -0.000835T + 1.0167 \tag{4.9}$$

$$For\ 200° \leq T \leq 800°C \qquad \frac{E_T}{E_{20}} = -0.00135T + 1.1201 \tag{4.10}$$

As one of the characteristics of steel is the hight expansion when heated, and the non-uniform variation of temperature across the stud section on LSF walls, thermal bowing will be developed in these structures in fire events, this way, a precise determination of the thermal properties of the material should be inserted in the finite element model. For these thermal properties, it was decided to be use the guidelines as specified by Eurocode 3.

Being so, the thermal expansion coefficient of the material was calculated using the equation 4.11, 4.12 and 4.13.

$$For\ 20° \leq T < 750°C \quad \alpha = 1.2 \times 10^{-5}T + 0.4 \times 10^{-8}T^2 - 2.416 \times 10^{-4} \tag{4.11}$$

$$For\ 750° \leq T \leq 860°C \qquad \alpha = 1.10 \times 10^{-2} \tag{4.12}$$

$$For\ 860° < T \leq 1200°C \qquad \alpha = 2.0 \times 10^{-5}T - 6.2 \times 10^{-3} \tag{4.13}$$

The specific heat was determined based on the equations 4.14, 4.15, 4.16 and 4.17.

$$For\ 20° \leq T < 600°C \quad C_a = 425 + 7.73 \times 10^{-1}T - 1.69 \times 10^{-3}T^2 + 2.22 \times 10^{-6}T^3 \ \left[\frac{J}{kgK}\right] \tag{4.14}$$

$$For\ 600° \leq T < 735°C \quad C_a = 666 + \frac{13002}{738-T} \quad \left[\frac{J}{kgK}\right] \tag{4.15}$$

$$For\ 735° \leq T < 900°C \quad C_a = 545 + \frac{17820}{T-731} \quad \left[\frac{J}{kgK}\right] \tag{4.16}$$

$$For\ 900° \leq T \leq 1200°C \quad C_a = 650 \qquad [\frac{J}{kgK}] \tag{4.17}$$

The last thermal property needed was the thermal conductivity, that was calculated using the equations 4.18 and 4.19.

$$For\ 20° \leq T < 800°C \quad \lambda_a = 54 - 3.33 \times 10^{-2} \quad [\frac{W}{mK}] \tag{4.18}$$

$$For\ 800° \leq T \leq 1200°C \quad \lambda_a = 27.3 \qquad [\frac{W}{mK}] \tag{4.19}$$

For the material properties of gypsum and glass fibre, it was used the material producer's information and the Rahmanian's 2011[19] study about the topic.

4.3.1.3 Study of the Mesh Size

A show by Gunalan and Mahendran in they work, the effects of mesh size is of great influence in the results of the simulations. In the research the authors realized a series of simulation with different sized mesh, using in the end a mesh of 4x4 mm of element edge.

In this work, a series of simulation with different sized mesh was also realized. After a careful study of the results and processing time, the conclusion was that the most advantageous mesh size, considering the precision and hardware restrictions, was a mesh of 10x10 mm of element edge. The table below presents the results obtained for the buckling (P_{cr}) and nonlinear (U) simulations with different element sizes.

Table 2: Comparison of simulations with different element size.

Element size [mm]	P_{cr} [kN]	U [kN]
--	39,8*	79**
10	40,76	85,55
8	40,33	81,72
6	40	80,66
4	39,8	78,89

*Result obtained by Gunalan and Mahendran in buckling analysis with elements of 4mm.

**Result obtained by Gunalan and Mahendran in non-linear with elements of 4mm.

4.3.1.4 Boundary Conditions

As in the fire tests, the LSF walls are pinned in both ends to the test setup, in the developmento of the model was also applied pinned support conditions in both ends of the studs. In the top track was applied restrictions to the movemente in all directions (Ux, Uy and Uz) and the rotation in the axis parallel to the height (Rotz) in all the nodes along the lenght of the track, in the bottom track was applied the same restrictions except the movement along the z axis (Uz), allowing the normal displacement of the studs.

Another restricton that was considered was the effect of the plasterboards in the lateral deformation of the studs. Its of agreement between several researchers that this restriction has a considerable effect and should be taken in acount in finite elemente models. This was, was applied to the model this lateral restrain in the form of the restriction of movemente in x axis (Ux) in the screws locations of the experimental specimens.

To simulate the effects of the loading frame on the structure behaviour, in the section of the track exactly below each stud, where was positioned the mechanical jacks in the experiment, it was applied a different material, with the fictional elastic modulus of 2100Gpa and a plate thickness of 14mm so the section would have a hight stiffness.

4.3.1.5 Simulations Results and Validation

4.3.1.5.1 Buckling Analysis

The figure 4.8 illustrates the finite element model after appling all the boundary conditions and other informations presented before and figure 4.9 details the local where was applied the load.

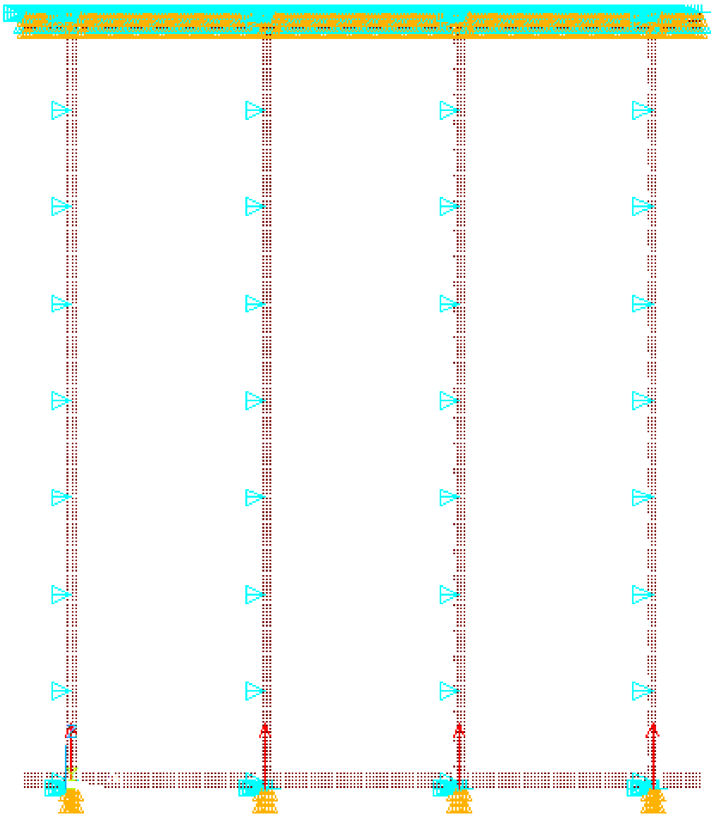

Figure 4.8: Finite element model

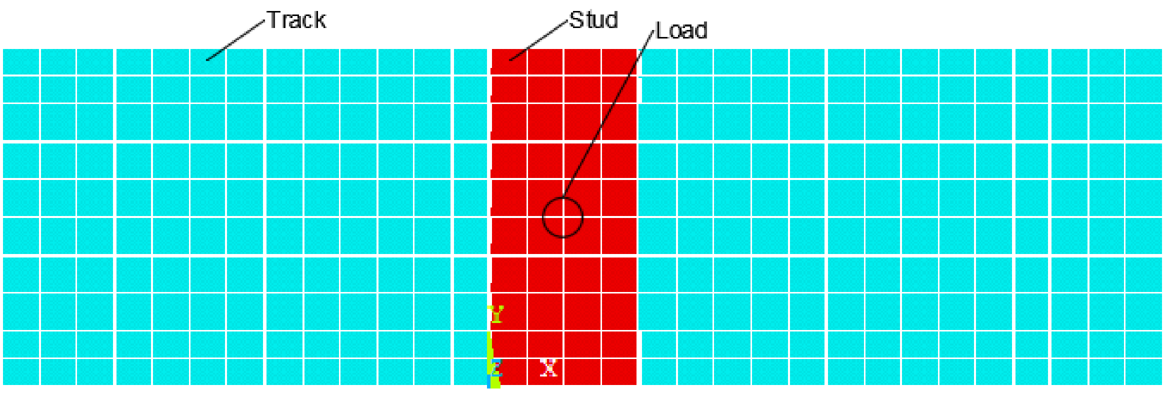

Figure 4.9: Detail of the applied load.

Based in ths model, the first simulation – the buckling analisis – was realised. With the final result being approximately 40.76 kN, and with local buckling in the web occuring, the buckling simulation showed the expected results. The figure below presents the deformation of the structure in the buckling analysis, wth a scale in the deformation to be better perceptible.

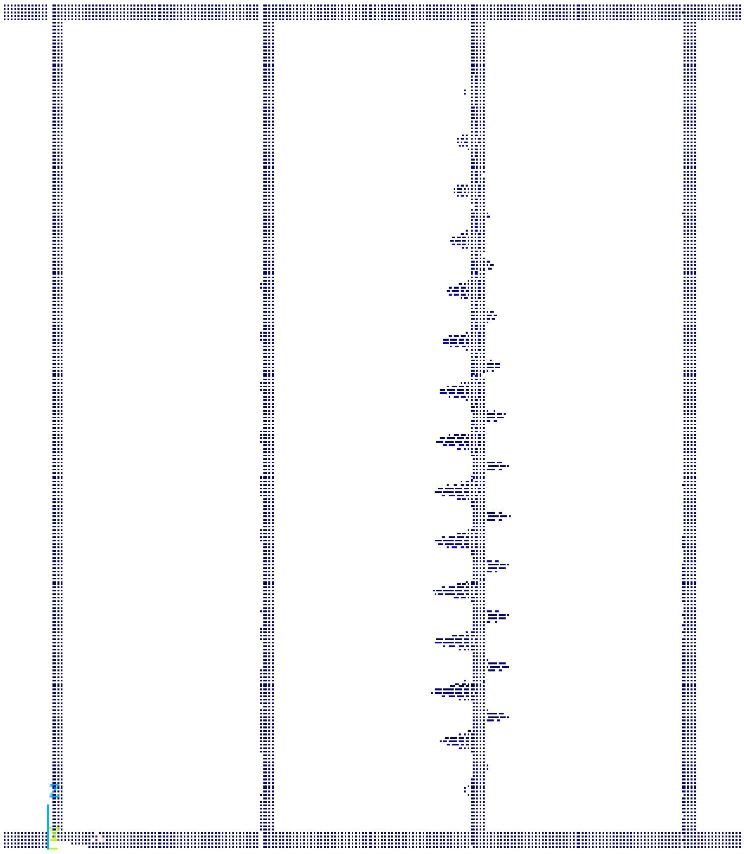

Figure 4.9: Buckling Analysis.

4.3.1.5.2 Non-linear Analysis

After using the equation 4.8 to apply the geometric imperfection in the model and inserting the perfect plastic behaviour of the material, the non-linear simulation was realised. The final result obtained for the ultimate load in the simulation was 85.55 kN.

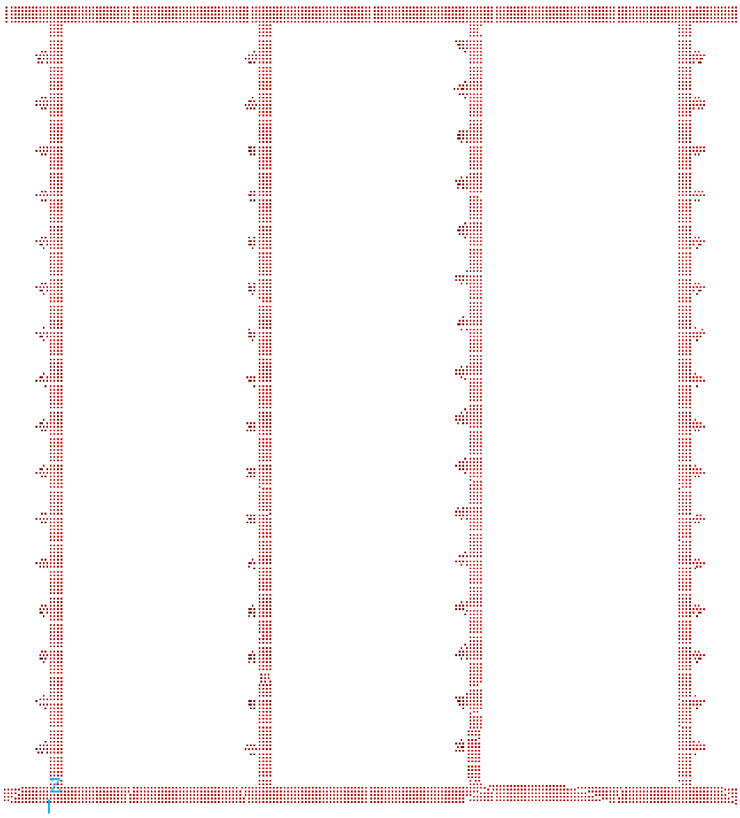

Figure 4.10: Non-linear Analysis.

As show in the figure above, the main deformation presented was the local web buckling. This is compatible with the behaviour of the structure in this type of situation.

When comparing deformation results obtained in the simulation with the results obtained by Gunalan and Mahendran in the research – both the FEA results and the experimental test results – it can be seen that the finite element model results are considerably close of each other. The experimental test results present a minor deformation, but it can be explained by the effect of external factors, like the minor increase in stiffness provided by the plasterboards or the loading method of the hydraulic jacks used in the experiment. Anyway, the ultimate load obtained in all three methods are comparably close.

The graphs below demonstrate the load-strain curve of the structure. Figure 4.11 presents the results of the model developed and Figure 4.12 presents the results of the model, Gunalan's FEA results and the experimental results.

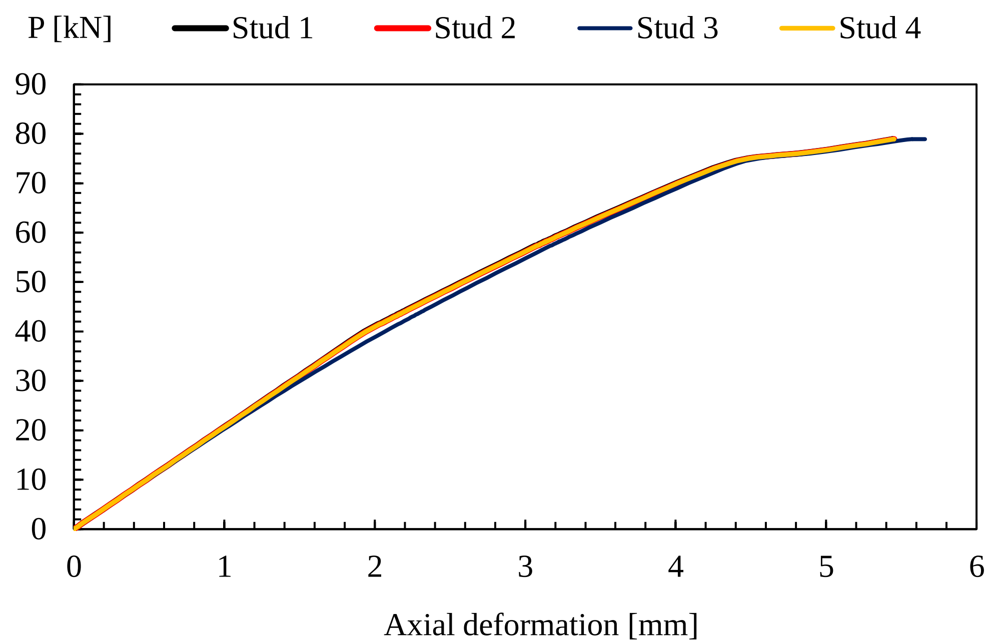

Figure 4.11: Results of non-linear simulation.

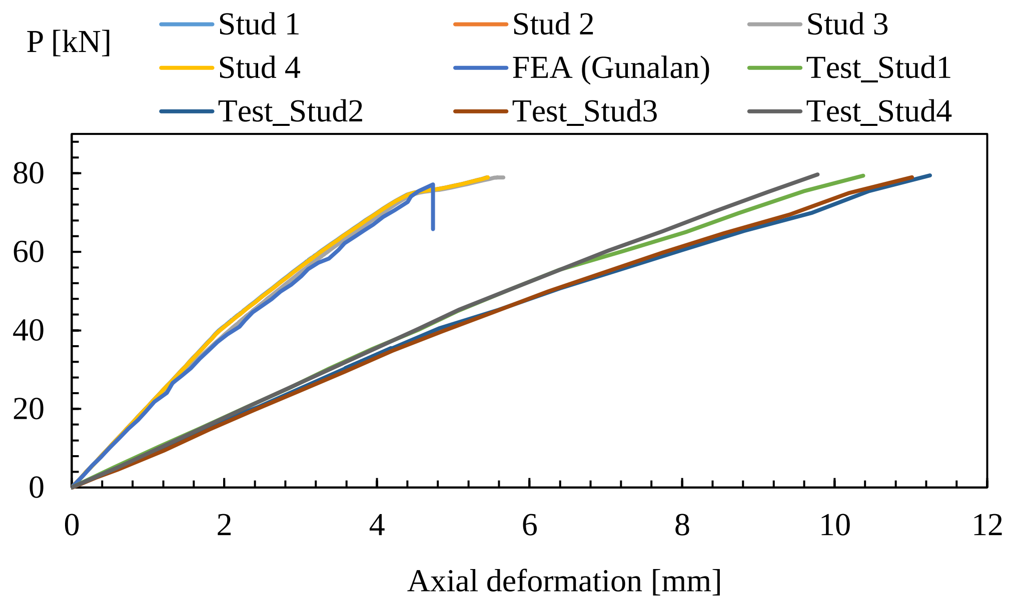

Figure 4.12: Comparison of the results.

4.3.1.5.3 Thermal Analysis

With the definition of the thermal properties of the materials and being applied all the boundary condions of the thermal analysis, the simulation was realised. The figure 4.13 and 4.14 presents the results of the simulation. The first one demostrates the evolution of temperature in exposed face (FS), unexposed face (AC), interface surface between boards (Pb1-Ins, Pb2-Ins, Pb3-Ins and Pb4-Ins) and cavity (Pb2-Cav and Pb3-Cav). The second, the evolution of temperature on studs 2 and 3 (middle studs), in their cold flange (CF), hot flange (HF) and web.

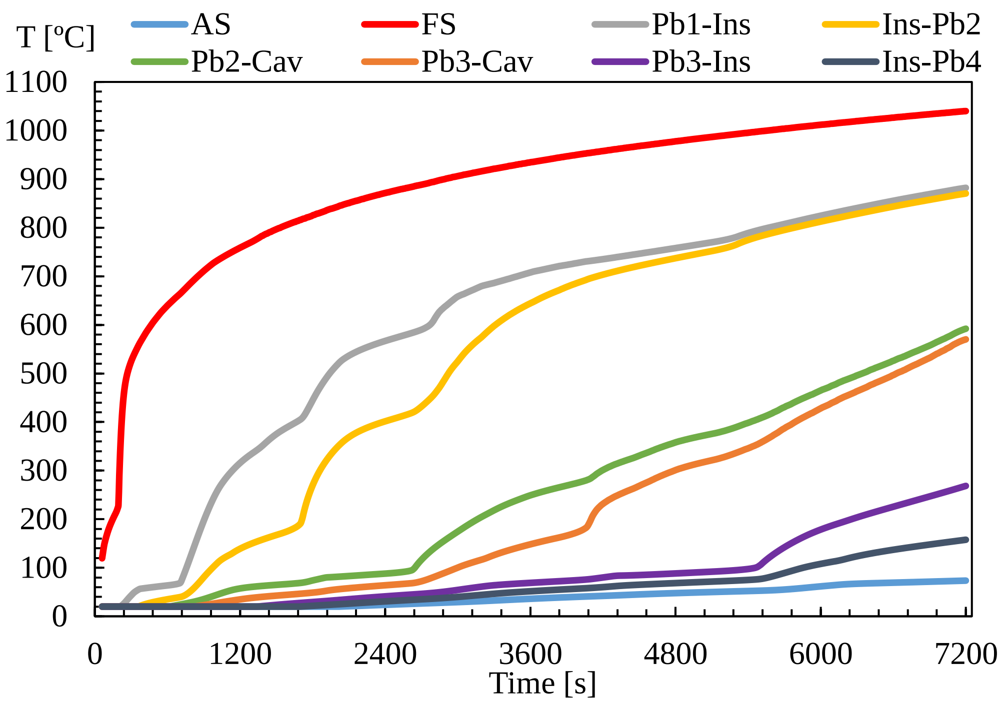

Figure 4.13: Evolution of temperature on surfaces.

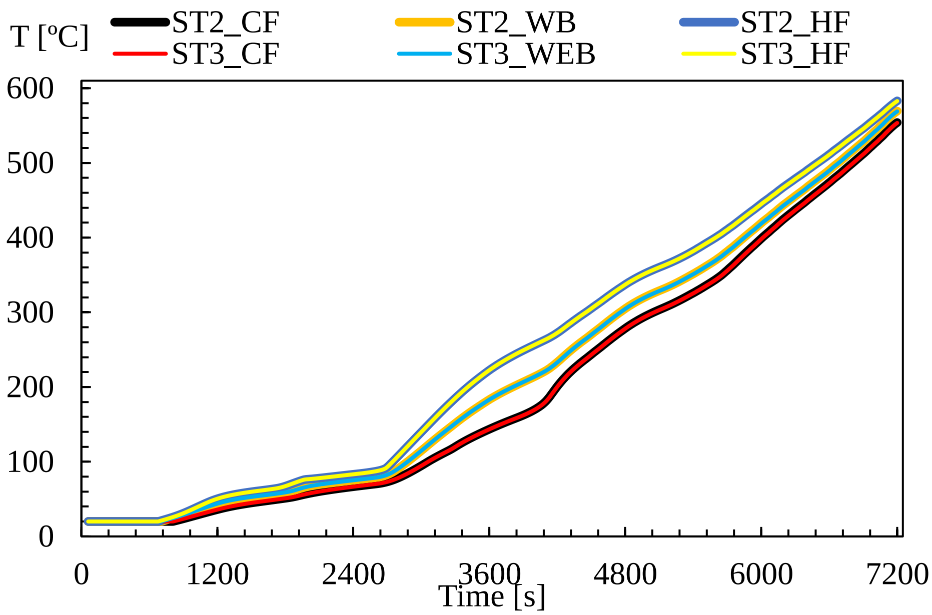

Figure 4.14: Evolution of temperature on studs.

Being figure 4.15 and 4.16 the evolution of temperature measured in the experimental test, its possible to realize a comparison of results, as illustrates figure 4.17 and 4.18.

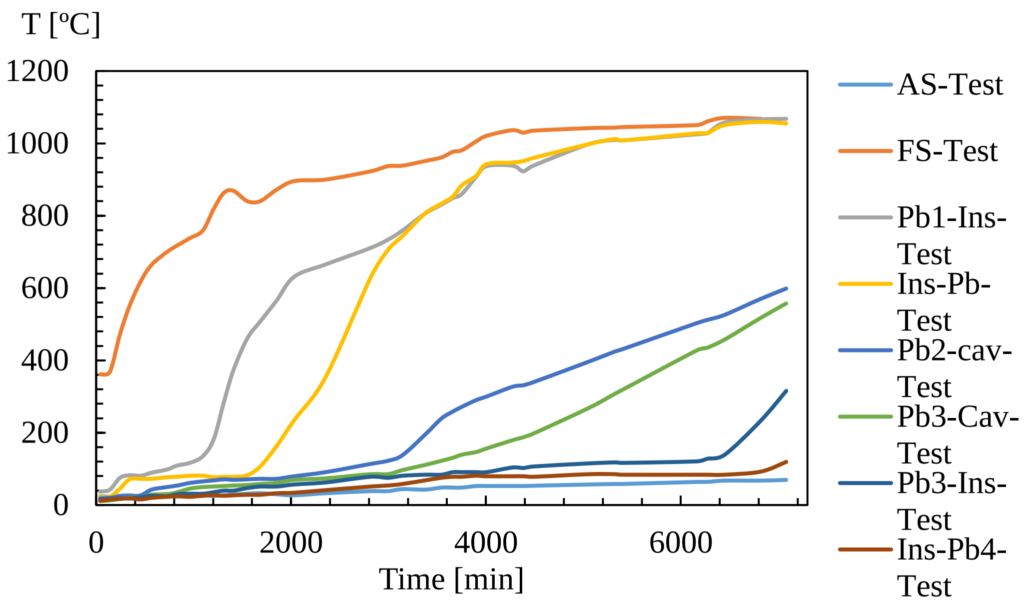

Figure 4.15: Evolution of temperature on surfaces (Experimental test).

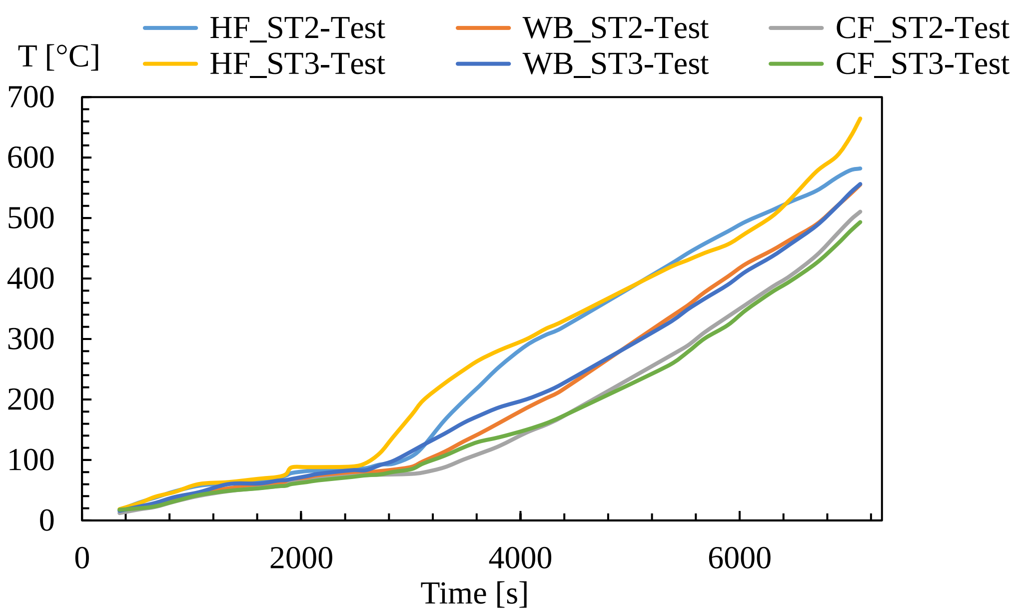

Figure 4.16: Evolution of temperature on studs (Experimental test).

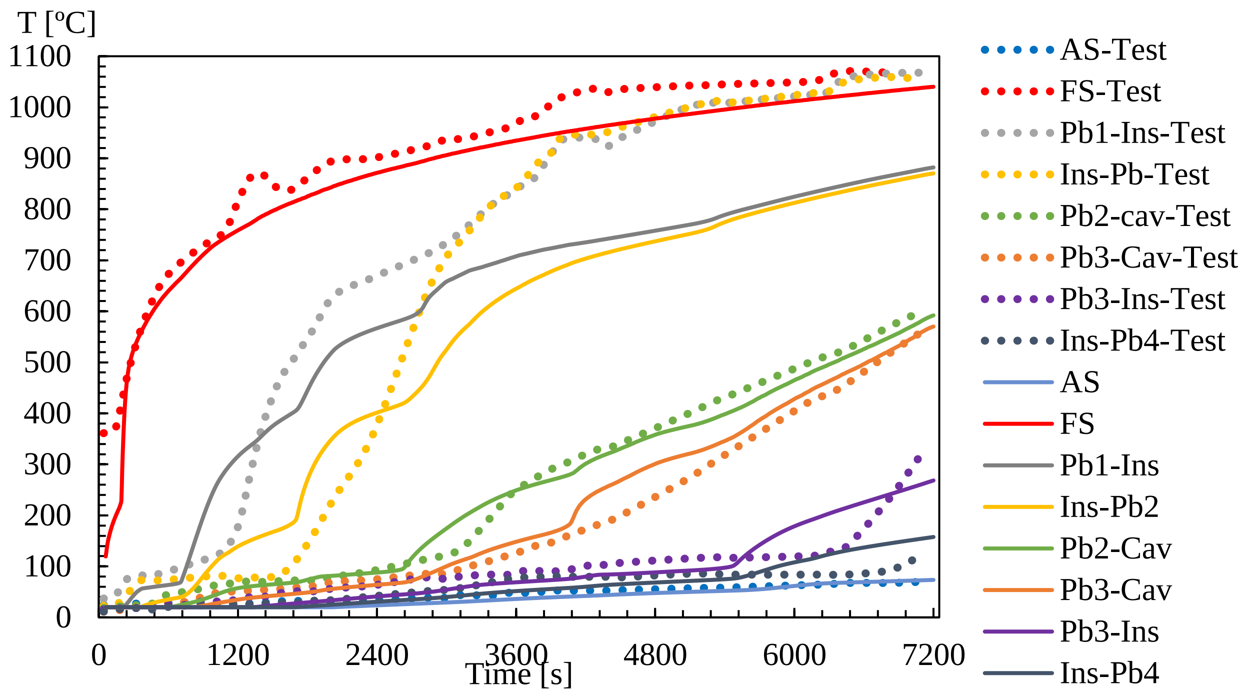

Figure 4.17: Comparison of temperature on surfaces.

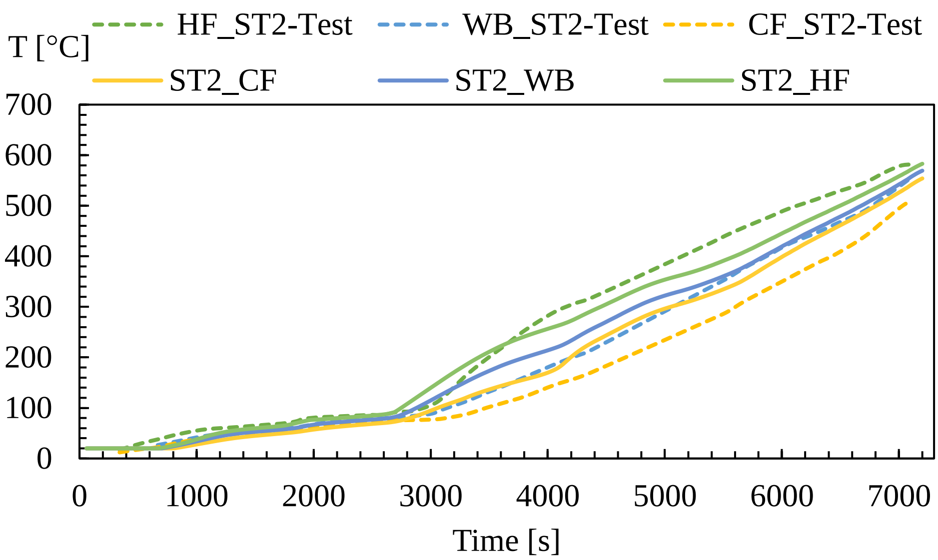

Figure 4.18: Comparison of temperature on studs.

Analyzing the comparison its possible to determine that the results of the simulation and the experimental tests are close. The evolution in temperature in the studs and cavity have a good approximation of the experimental test, what garantees a good simulation of the effects of temperature in the mechanical properties of the material.

Another comparison that can be made is related to the insulation criteria of EN 1363-1. The figure 4.19 presents the evolution of the average temperature in the simulation and in the experimental test, it also demonstrates the increase of the max temperature of the simulation. The standard criteria are also marked in the figure. As can be observed, in neither the experimental test or in the model, the insulation criteria in defined as have failed.

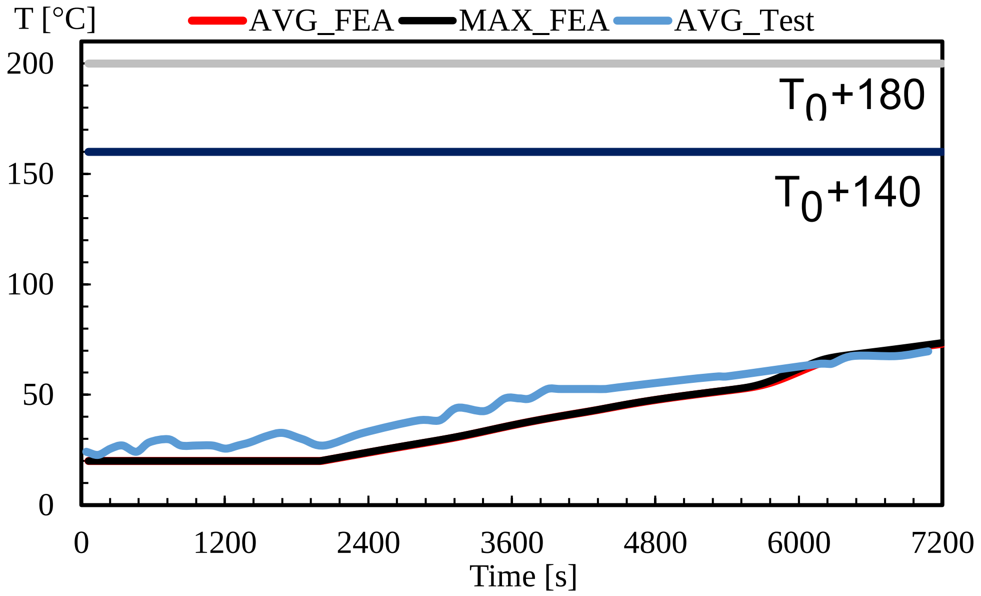

Figure 4.19: Insulation criteria.

Using the results obtained in the thermal simulation, the thermo-mechanical simulation was realized. In the experimental test, Gunalan and Mahendran applied the load of 15kN, as a ratio of the ultimate load, so the same load was applied to the model. The figure bellow shows the axial displacement of the wall through time obtained in the simulation, it also presents the results obtained by the authors in the FEA and experimental test.

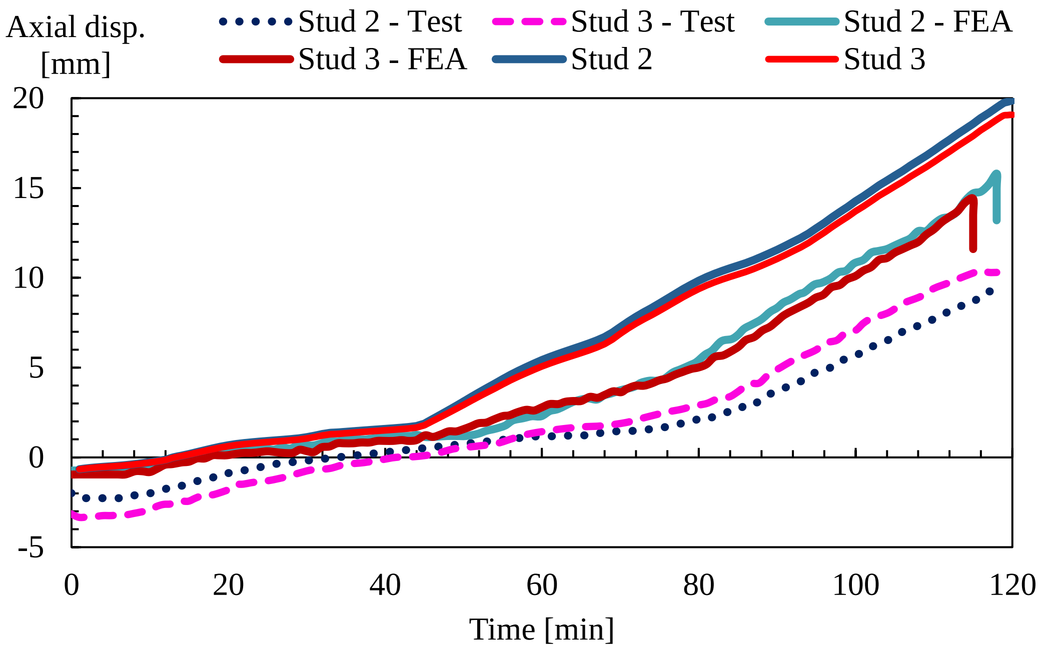

Figure 4.20: Comparison of experimental and mathematical model results.

As can be observed, the simulations have a good agreement in the results. The experimental test presented a greater displacement in the beggining of the test, but it can be explained by the compactation of the material used to conect the wall to the loading frame. Overall, the results have a acceptable agreement between each other.

Using the "root mean squared error" – equation 4.20 – to calculate the error between this thesis model and the experimental test and the research's model, it was determined that a error of 11% was present in the model. Being a relatively small error, it can be assumaed tha validation of the model as proved.

$$RMSPE = \sqrt{\frac{1}{n}\left[\sum_{n=1}^{n}\left(\frac{S_t - A_t}{A_t}\right)^2\right]} \times 100\% \qquad (4.20)$$

Chapter 5. Parametric Analysis

After the development of the model, a series of parametric analysis was made to identify the effects of plasterboard thickness and steel section in the fire behaviour of light steel frame walls.

In this chapter will be presented these studies and its conclusions.

5.1 Influence of the panel's Thickness

The influence of the thickness of the panels in the protection of structures are crucial for the design of a LSF wall in fire condition. For this, it was realised simulation using, not only the 16mm thick plasterboard of the model initial design, but also other commercial board, with 12.5mm thickness.

The results of the simulations with the two types of panels are presented below. Being case 1 using the 16mm thick board and case 2 the 12mm thick board.

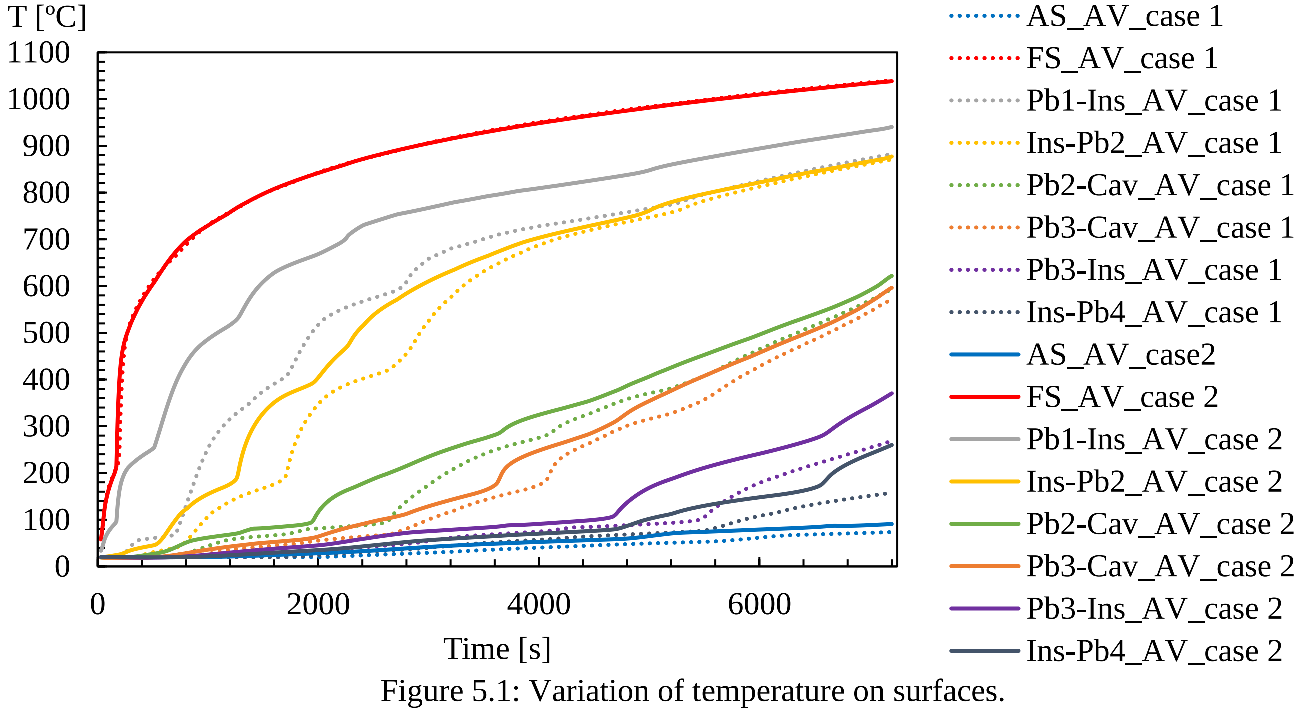

Figure 5.1: Variation of temperature on surfaces.

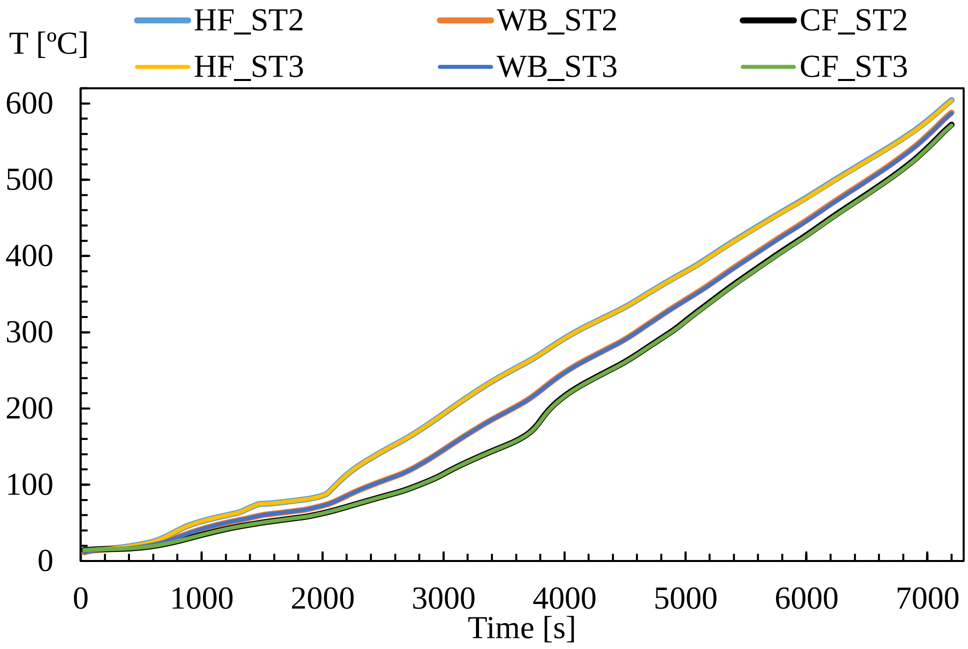

Figure 5.2: Variation of temperature on studs.

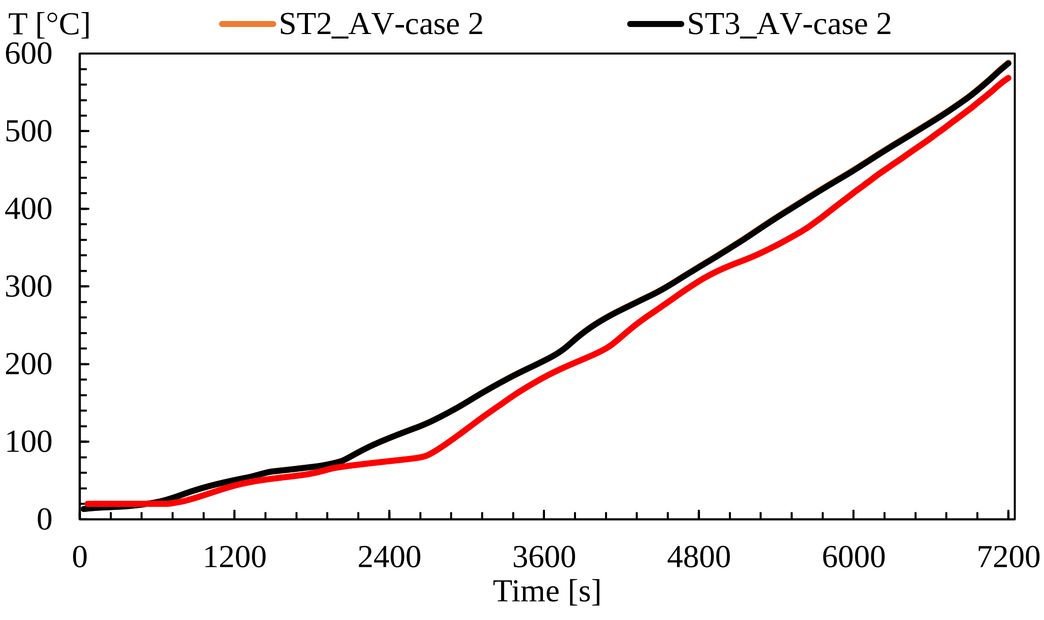

Figure 5.3: Avarage of temperature on studs.

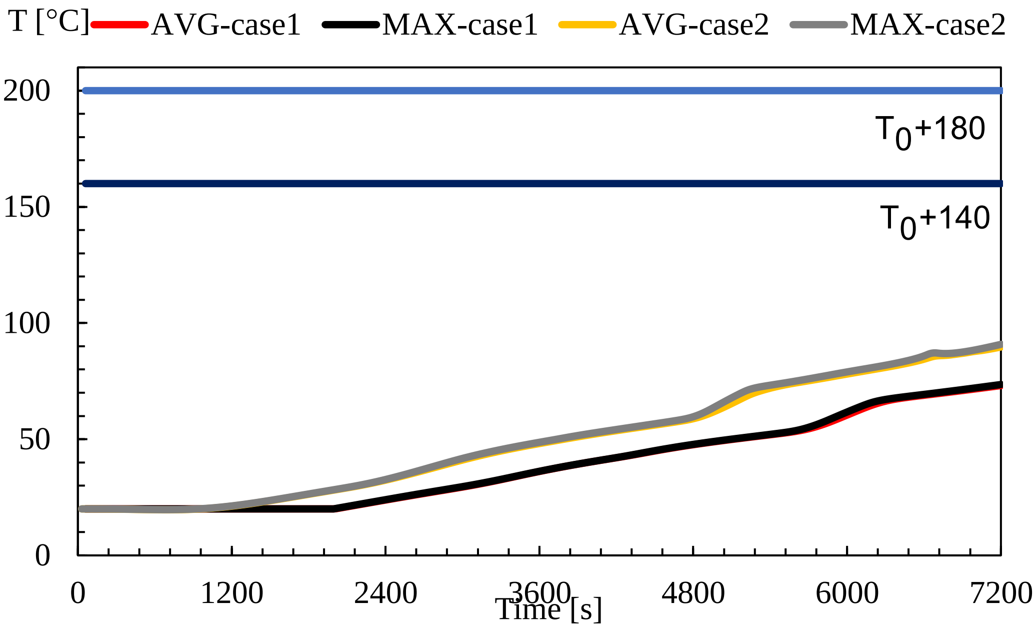

Figure 5.4: Insulation criteria.

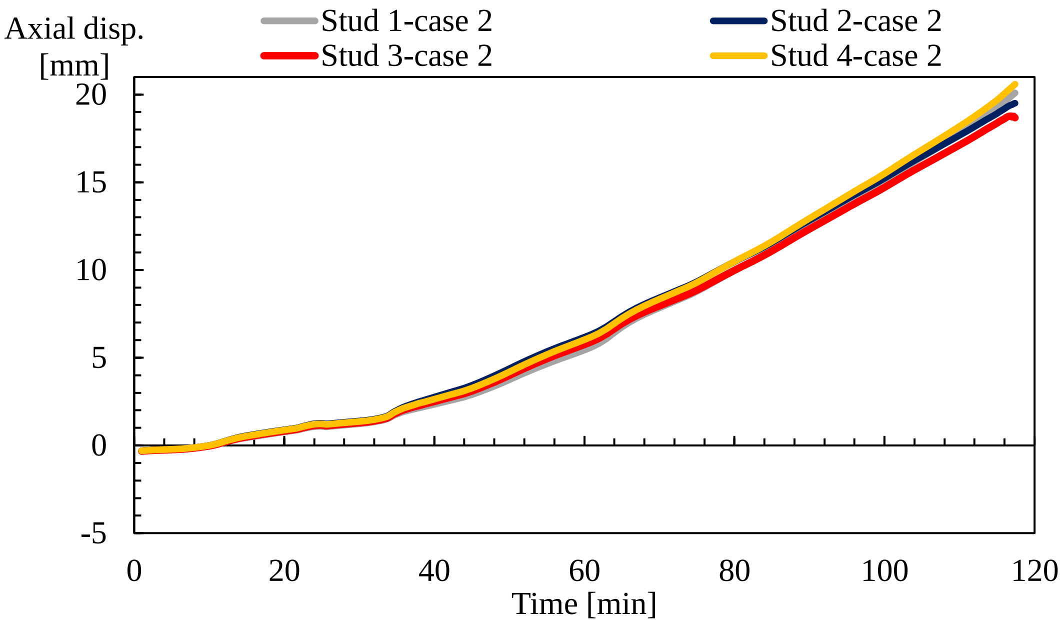

Figure 5.5: Axial displacement on studs.

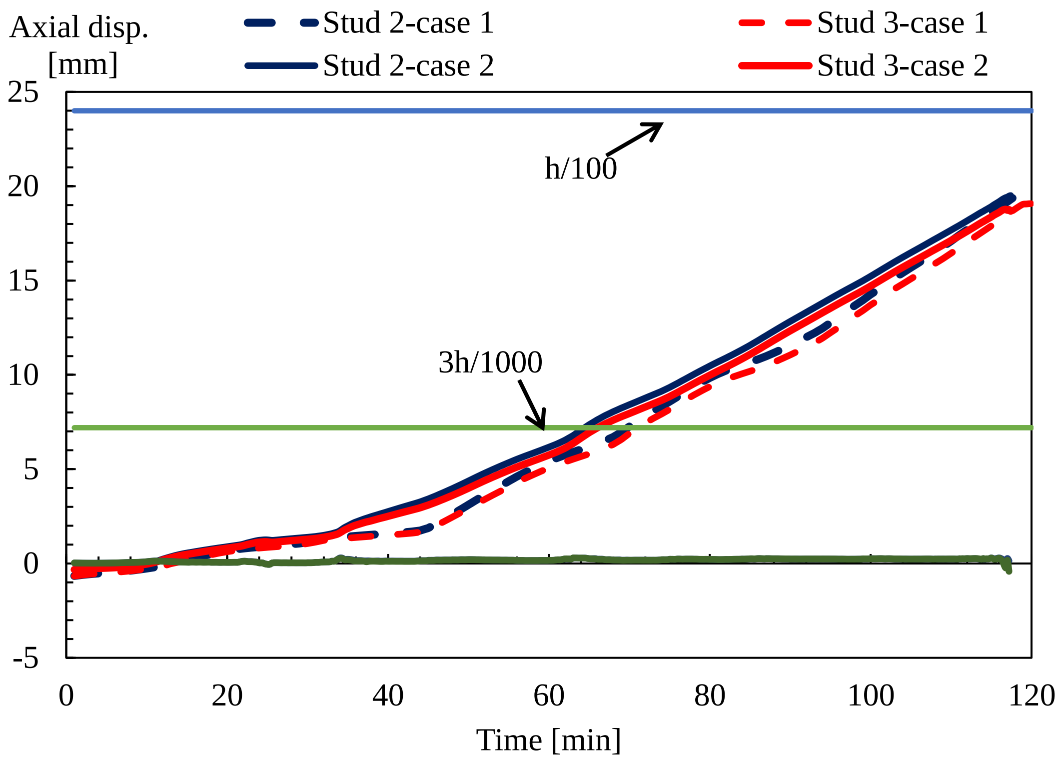

Figure 5.6: Resistance criteria.

As can be observed in the results, the wall with board with 12.5mm presents a worse insulation capacity than the 16mm board as expected, with a temperature variation of approximately 3.5% higher. But even so, the effects of this higher variation are not of great significant for the overall wall behaviour. Figures 5.4 and 5.6 shows that even with this difference, the insulation and loadbearing criterias do not fail.

5.2 Influence of the Steel Section

The steel section used in the construction of the structure is not of big influence on the thermal capacities of the wall, but is related to its loadbearing capacities and so, direct related to its fire resistence rating. This way, simulations using section with 1.5 and 2mm thick steel plates were made to determine this influence.

Figure 5.7 presents the axial displacement with the increase of the applied load in all studs of each case analyzed. In figure 5.8 the same results are presented but only for stud 3 – one of the middle studs – to be easier observed the relation between the steel section and the stiffness of the structure.

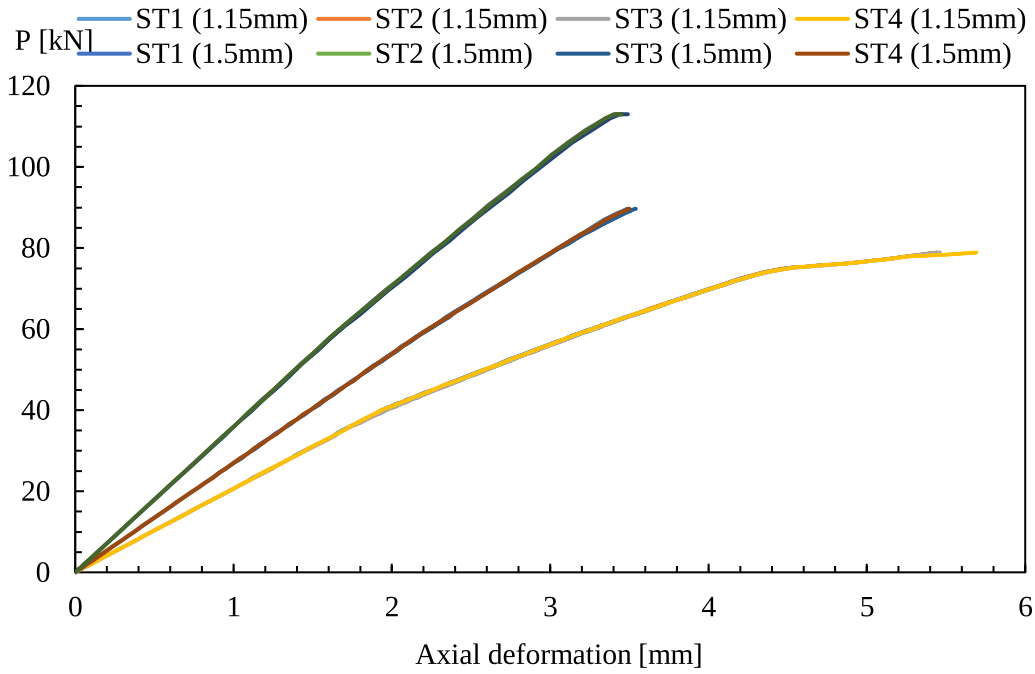

Figure 5.7: Axial deformation in all studs.

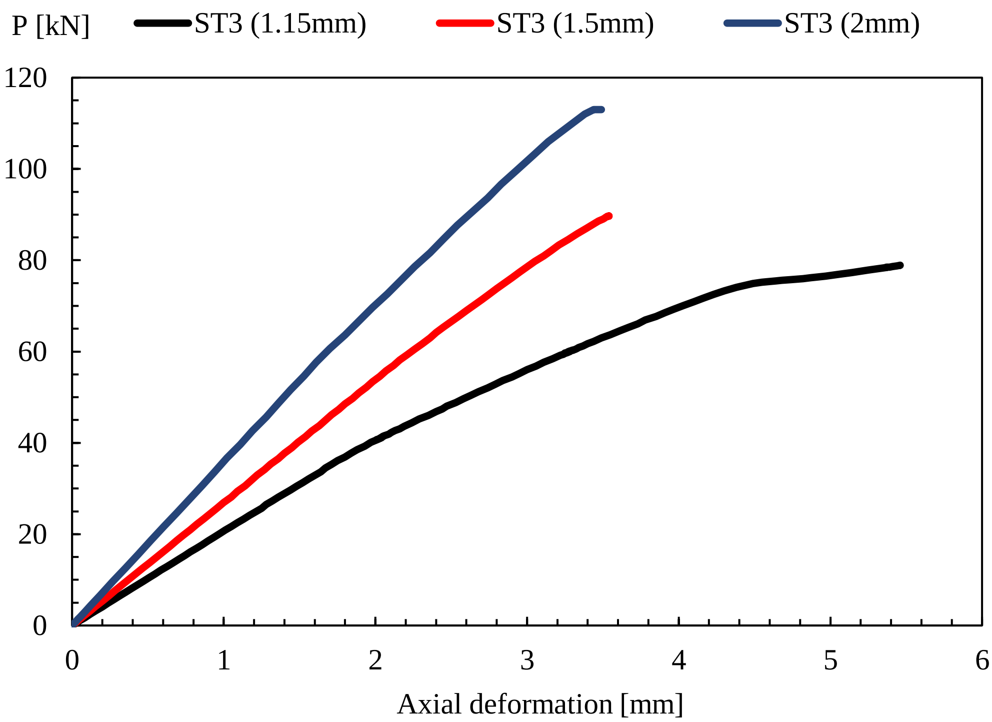

Figure 5.8: Axial deformation in stud 3.

As expected, the plate thickness is directed related to the loadbearing capacities of the wall. In the structure with 1.5mm and 2mm of thickness is observed that the axial displacement is approximately 44.44% and 58.15% less than the 1.15mm thick structure for the same load level respectively. This way, it can be assumed that the use of studs section of higher plate thickness would imply in a better fire resistance rating.

Chapter 6. Design of the Experimental Test Setup

With the last results as base, it was developed the setup to be used in experimental tests of loadbearing walls in the laboratory of the institution where was made this thesis, Instituto Politecnico de Bragança.

In this chapter will be presented the geometry conception, and the design of the supporting frame.

6.1 Reference Load

Taking as base the model developed, a simulation of a wall with dimensions of the the future experimental specimens posible to be tested in the funace of the institute was realized.

With dimensions of 1x1m and three studs, space between each other by 500mm, the wall simulated presented a ultimate load of approximatelly 89.4kN per stud..

This way, the load of 90kN will be adopted as the reference load to the design of the loading frame.

6.2 Geometry

With the load defined the next step of the design was the geometry conception of the frame. As said before, with the furnace limitations the maximum dimension of the specimens that can be tested was 1x1m, this way, it was determined that a Universal Beam , where the structure would be fixed, with 1.1 meters of lenght, atached to two Universal Coluns, leaving 1.1 meters of extention for fixing the wall. The figure 6.1 shows the schme of the loading frame.

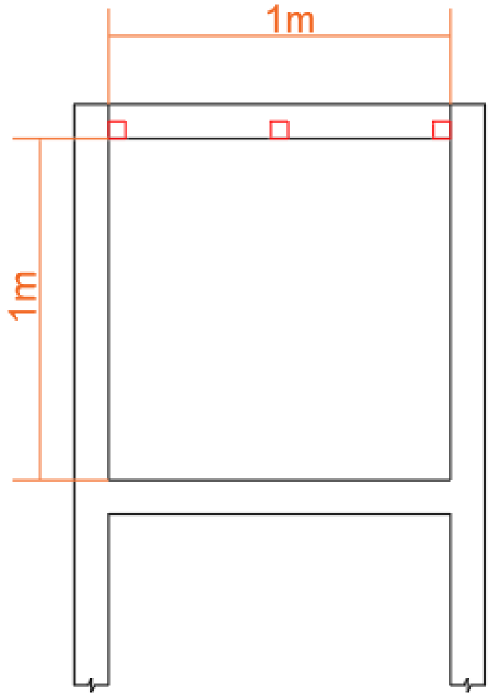

Figure 6.1: Loading Frame.

6.3 *Cross Section Definition*

With the definition of the geometry, a series of simple static analysis was made using the software *Ftool*. Capable of determine the axial, shear and bending moment diagrams of the structure, this analysis enable the determination of the cross section with simple comparisons with the normative charactistics of the commercial section available.

The figures below presents the loading and suppoting conditions that were assumed and the internal forces diagrams.

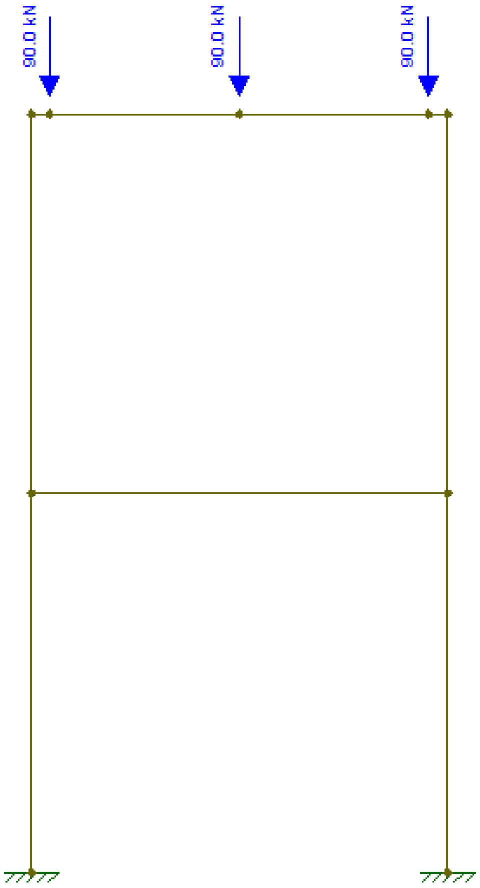

Figure 6.3: Loading conditions.

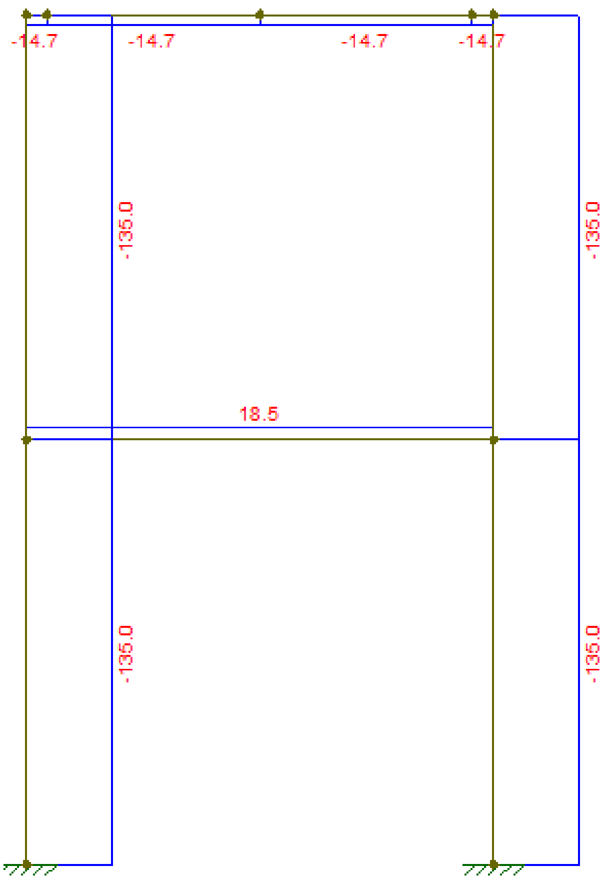

Figure 6.2:Axial force.

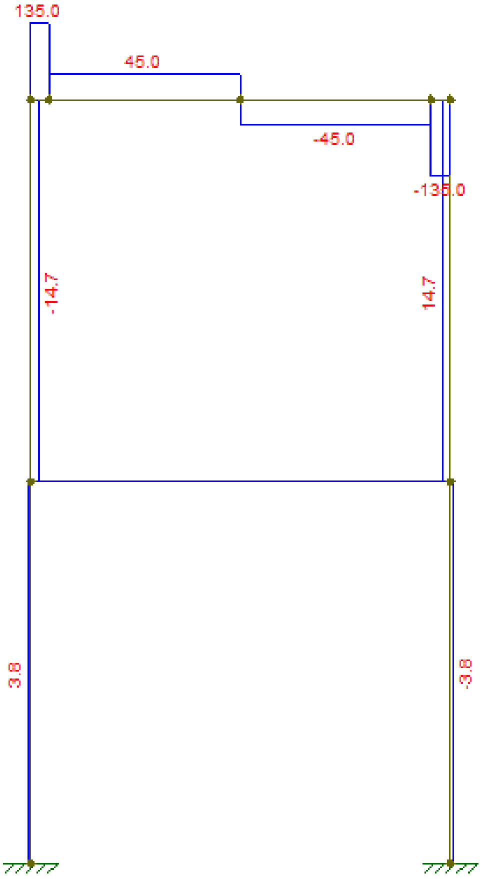

Figure 6.5: Shear Force.

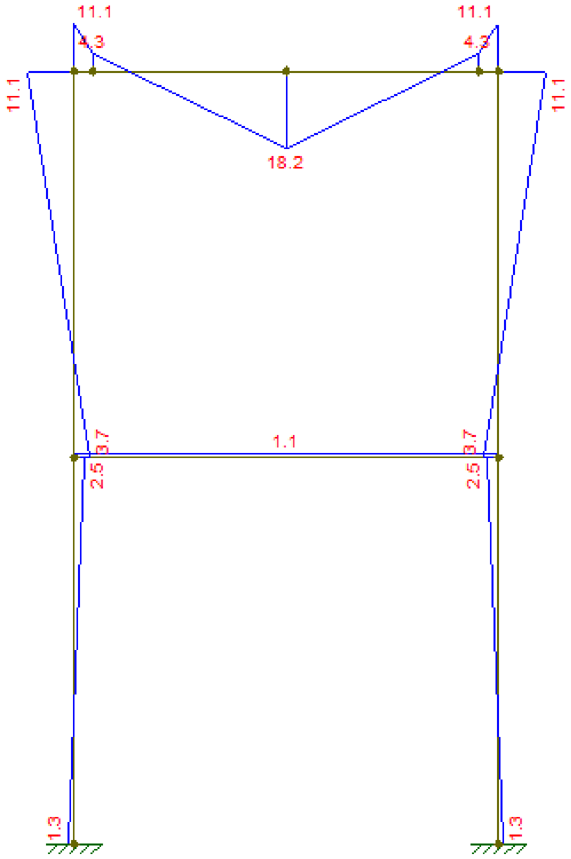

Figure 6.4: Bending moment.

After a consideration of the situation of the furnace, laboratory facilities and the structure geometry, it was defined that a HEA or HEB steel section would be appropriete. With this and the internal forces determined, it ws possibe to define the section to be used. The tables 3 and 4 shows the characteristics of some of the HEA and HEB sections available.

Table 3: HEA section.

Section	Second Moment of Area (cm^4)		Elastic Section Modulus (cm^3)	
	x-axis	y-axis	x-axis	y-axis
140	1033	389	155	56
160	1673	616	220	77
180	2510	925	294	103
200	3692	1336	389	134
220	5410	1955	515	178
240	7763	2769	675	231
260	10455	3668	836	228
280	13455	4763	1010	340
300	18263	6310	1260	421

Table 4: HEB section.

Section	Second Moment of Area (cm^4)		Elastic Section Modulus (cm^3)	
	x-axis	y-axis	x-axis	y-axis
140	1509	550	216	103
160	2492	889	311	134

180	3831	1363	426	178
200	5696	2003	570	231
220	8091	2843	736	228
240	11259	3923	938	340
260	14919	5135	1150	421
280	19270	6595	1380	471
300	25166	8563	1680	571

Comparing all the data obtained, was conclued that the use of beams and colluns with a section HEB220 would be a good choice.

Inserting the characteristics of the section and the material in tthe analysis, was calculated the displacement genarete by reference load. As was indicate in the standard previously, it was also determined the displacement created by the use of a 10kN force on mid span of the structure.

As can be observed in the figures, in both situations the displacement is negligible, being close to 0.24mm for the reference load and less than 0,02mm for the 10kN load, showing that in the standard situation the 1mm maximum deflaction was not violated.

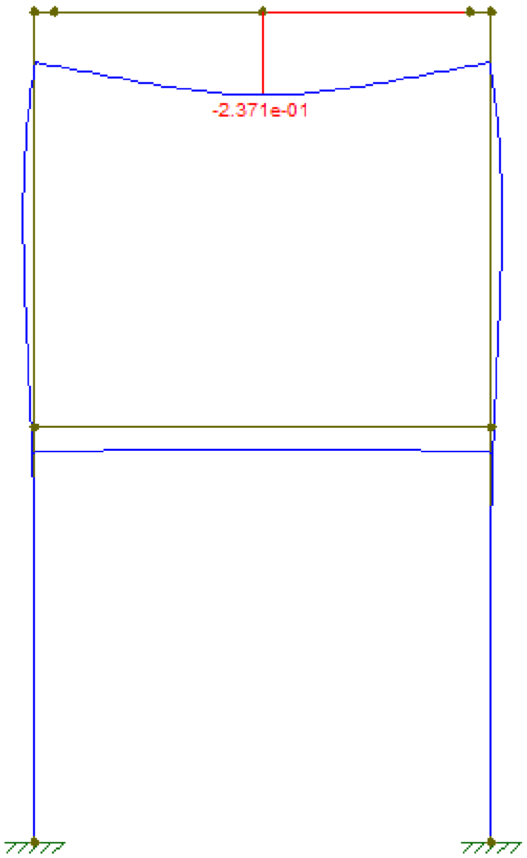

Figure 6.7: Displacement – Reference load.

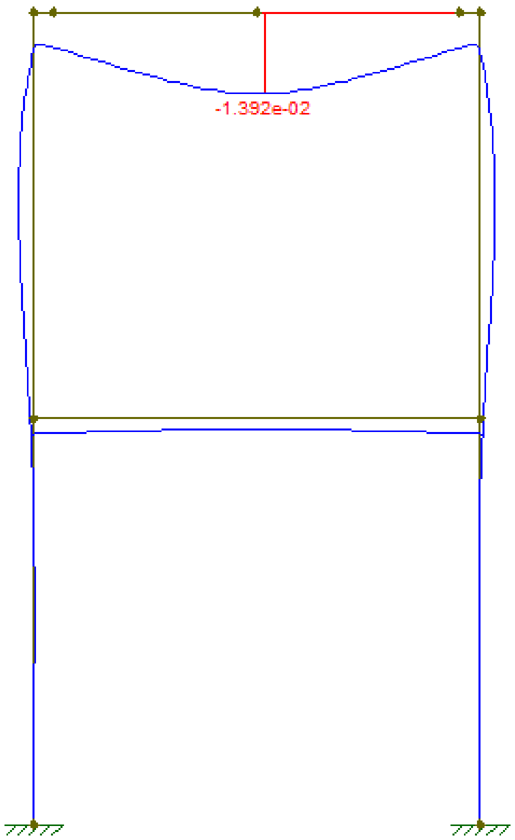

Figure 6.6: Displacement – 10kN mid span.

6.4 Hydraulic Jacks

After the definition of the structure, the last step on the design of the experimental test was the definition of a hydraulic jack to be used.

As is expected, the use of a large instrument with a great area of aplication of force and a capacitie limitation to close to the reference load is not much desirable. This way, a search for a compact hydraulic jack with loading capacity of about 100kN was realized

The figure below presents a catalog of hydraulic jacks manufacture by *ENERPAC*. This hydraulic jack has a capacity of 10 tons – so approximately 101kN - and a 11mm stroke weighting 1.4 kg, this way, little impact on the experiment.

Figure 6.8: RSM100

With three of the defined jack positioned in the expected stud position, and the control of load by the operator. Is expected a good result in the experimental test. In the instalation of the device, a method to insulate the jacks from the heat of the furnace should be prepared.

Chapter 7. Conclusion

7.1 Conclusion

This work presented the study of the behaviour of loadbearing Light Steel Frame Walls in fire events through the development of a finite element model and a set of parametric analysis to evaluate de effects of steel section and plasterboard thickness in the fire resistance. The analysis made indicate that both types of characteristics are of some importance in the rating.

The thickness of the plasterboard showed a variation of temperature of 3.5% between the boards with 16mm and 12.5mm, being posible to infer that the variation of temperature using composite panels with gypsum plasterboards should be approximatelly 1%/mm of thickness of the board. This minor influence can be explained by the geometry of the composite panel used, as the insulation being positioned between the gypsum boards create a lesser effect of the thickness, but this also can be deduced as a possible problem. Its probable that with the use of thinner boards the insulation would be consumed soonner and would lead to a higher varation of temperature that was obtained through simulation.

The steel section presented negligible effect on the temperature variation, but is of great importance in the fire rating, as it increase the mechanical resistance of the wall. The simulations showed that the increase of the plate thickness from 1.15mm to 2mm leaded to a decrease of 58.15% in the axial displacement for the same load. As consequecence, a great increase of the fire resisance of the wall is to be expected.

7.2 Future Topics of Study

As this thesis worked with the development of a finite element model and the design of the experimental test setup of a loadbearing LSF wall in fire conditions, one of posibles future works is the costruction and experimental test of specimens to be tested in the institute facilities. This experimental researchs would help to increase the understantind of the behaviour of loadbearing LSF wall in fire events, leading to possiblely de development of new empirical and simplified models of calculate the fire resistance of this type of element.

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